

Western Kentucky University Air Travel Emissions Calculation Methodology
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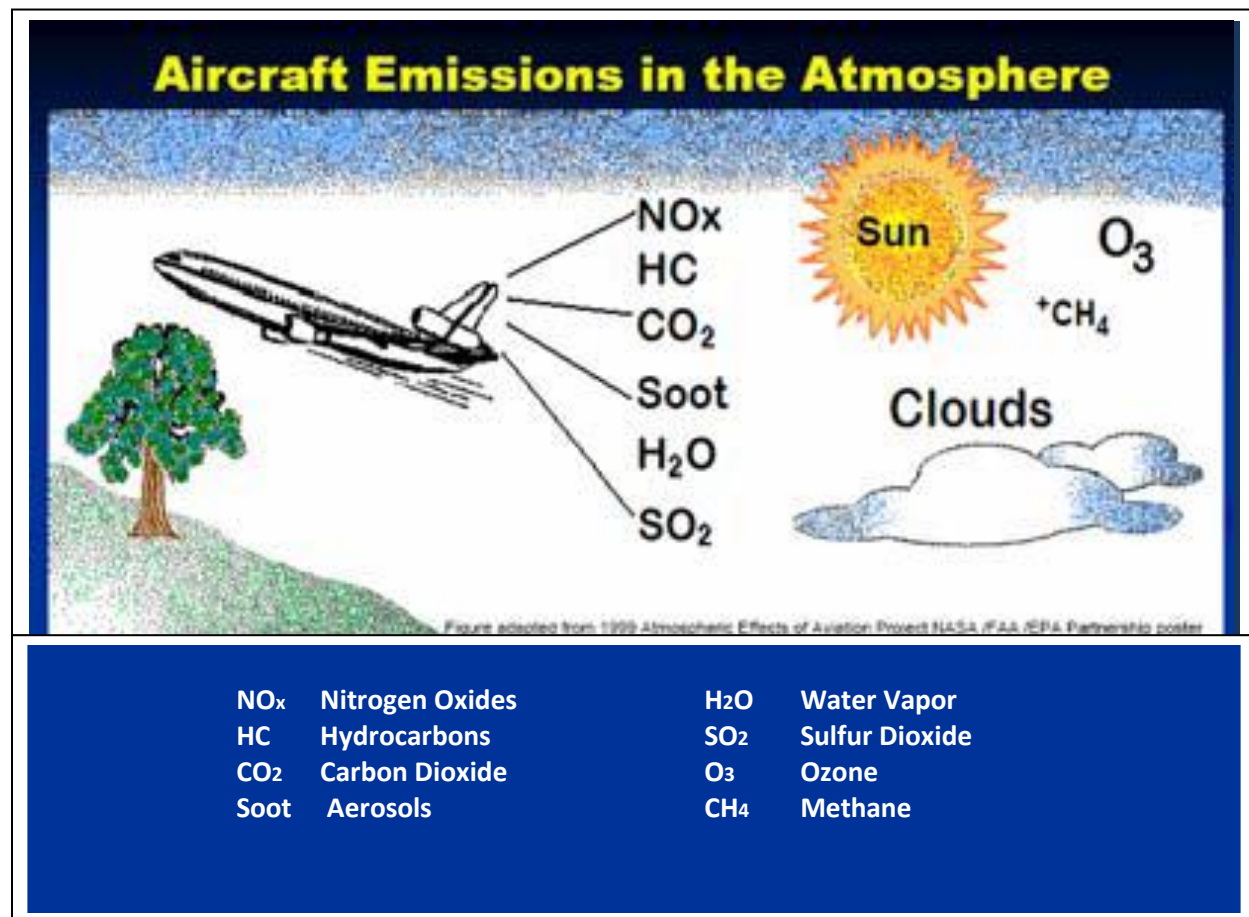
There is great uncertainty in determining a meaningful way to measure the effect air travel can have on the environment. More specifically, there is uncertainty in determining the degree to which air travel contributes to climate change due to green house gas (GHG) emissions. Listed below is a selection of terms that will be helpful in understanding some of the common terminology associated with measuring emissions. Most of the terms were defined by the Energy Information Administration, and the remaining terms were summarized by the Bonneville Environmental Foundation from a popular publication, *Aviation and the Global Atmosphere* (EIA, 2011 and BEF, 2011).

Climate Change	Refers to temperature changes experienced at the earth's surface as a result of chemical changes in the composition of the earth's atmosphere. When the amount of energy reaching the earth exceeds the amount leaving the earth, the net effect is warming.
Emissions	Anthropogenic releases of gases to the atmosphere. In the context of global climate change, they consist of radiatively important greenhouse gases (e.g., the release of carbon dioxide during fuel combustion).
Greenhouse Gases	Those gases, such as water vapor, carbon dioxide, nitrous oxide, methane, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride, that are transparent to solar (short-wave) radiation but opaque to long-wave (infrared) radiation, thus preventing long-wave radiant energy from leaving Earth's atmosphere. The net effect is a trapping of absorbed radiation and a tendency to warm the planet's surface.
Greenhouse Effect	The result of water vapor, carbon dioxide, and other atmospheric gases trapping radiant (infrared) energy, thereby keeping the Earth's surface warmer than it would otherwise be. Greenhouse gases within the lower levels of the atmosphere trap infrared radiation that would otherwise escape into space, and subsequent re-radiation of some of the energy back to the Earth maintains higher surface temperatures than would occur if the gases were absent.
Emissions Coefficient	A unique value for scaling emissions to activity data in terms of a standard rate of emissions per unit of activity (e.g., pounds of carbon dioxide emissions per unit of fossil fuel consumed).
Radiative Forcing	Refers to how much a particular activity contributes directly to the atmospheric chemical reactions that cause climate change. A higher radiative forcing index (RFI) means an activity has a greater contribution to chemical changes in the atmosphere. All human-influenced, or anthropogenic, emissions (i.e. automobiles, electric power plants, air travel) have an RFI associated with them.

Precise emission calculations are difficult to generate for air travel in particular because it involves many variables such as approximating the average size and type of aircraft, the average number of passengers on each flight, the fuel usage per mile, the altitude at which the aircraft is flown, the chemical reactions of GHGs in the atmosphere, the increase in natural chemical reactions, and much more. One well known publication, *Aviation and the Global Atmosphere*, has intensely researched

effects air travel can have on the environment. The special report was written by the Intergovernmental Panel on Climate Change (IPCC) in response to a request from the International Civil Aviation Organization to better understand the relevant science of the atmosphere, aviation technology, and socio-economic issues associated with mitigation options. The IPCC's reports have become standard works of reference, widely used by policymakers, scientists, and other experts. (Penner, Lister, Griggs, Dokken, and McFarland, 1999).

The more advanced methods of measuring the emissions related to air travel evaluate the carbon dioxide equivalent (CO₂e) emissions. CO₂e describes the global warming potential of various GHGs in comparison to the entire molecule of carbon dioxide (EPA, 2011). This helps to better approximate the total effect that GHG emissions have on the atmosphere. The picture below visually depicts the various GHGs that are released from aircrafts.

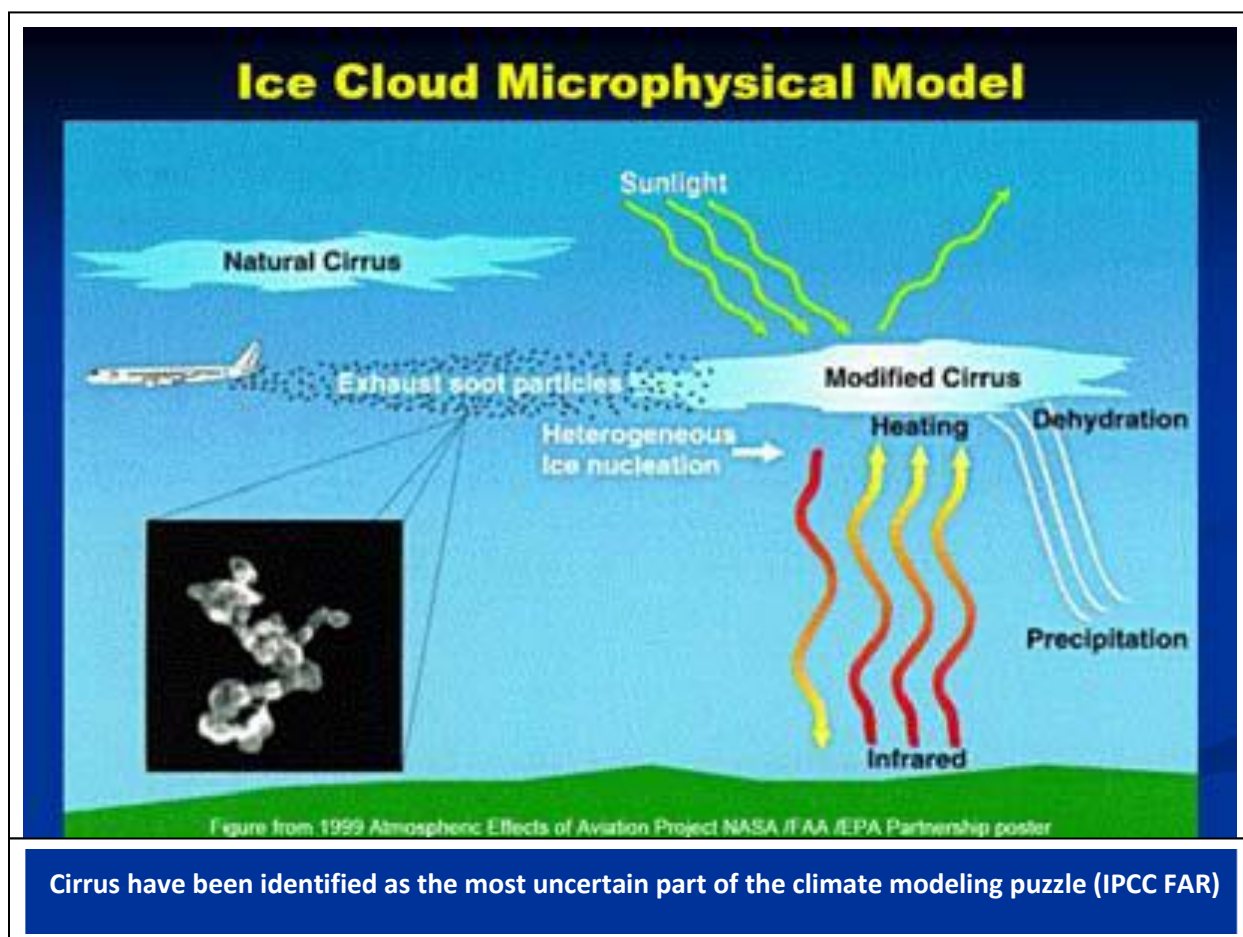


(Maurice, Holsclaw, Locke, Waitz, Lukachko, & Miake-Lye, 2005)

Most present-day jet aircraft cruise in an altitude range that interacts with the upper troposphere (UT) and lower stratosphere (LS), and as a result the GHG's react differently when released in these two atmospheric regions as compared to the surface (Penner, Lister, Griggs, Dokken, and McFarland, 1999). Therefore, a radiative forcing index (RFI) has been established to take into account the increased effect GHG's can have when emitted directly into the upper atmosphere. The IPCC defines radiative forcing as "the global, annual mean radiative imbalance to the Earth's climate system caused by human activities; it predicts changes to the global mean surface temperature" (Penner, Lister, Griggs, Dokken, and McFarland, 1999). A positive RFI indicates that the overall result will have a net

warming effect while a negative RFI will have a net cooling effect. Once the effects of GHGs have been analyzed, an average RFI can be calculated.

Much like GHGs, cloud formations can have an effect on the climate, depending on their density and altitude (Marian Koshland Science Museum, 2011). For example, high thin clouds may increase warming by trapping infrared radiation, while thick low-level clouds may cool the Earth by reflecting sunlight (Marian Koshland Science Museum, 2011). One cloud formation in particular has been proven to have an overall warming effect, cirrus clouds. These are conformed mainly by ice crystals and are described as thin, wispy clouds that form naturally at the highest of altitudes and generate an overall warming effect. In regards to air travel, the water vapor and aerosols that are released when aircrafts form contrails, also known as condensation trails. Contrails are “linear ice clouds formed in the wake of aircraft, which, when persistent, can result in the formation of cirrus cloud cover” (CORE, 2011). The model below illustrates the warming effect cirrus clouds and modified cirrus clouds caused by air travel can have on the climate.



(Maurice, Holsclaw, Locke, Waitz, Lukachko, & Miake-Lye, 2005)

The ICPP defines Aviation-induced cloudiness (AIC) as the sum of all changes in cloudiness associated with aviation operations which includes persistent contrail cover. It has been determined that contrails, a component of AIC, are indistinguishable from background cirrus clouds, and this ambiguity prevents AIC amounts from being included in the RFI (Forster, Ramaswamy, Artaxo, Bernsten, Betts, Haywood, Lean, Lowe, Myhre, Nganga, Prinn, Raga, Schulz, and Van Dorland, 2007). According to Carbon Offset Research & Education, cirrus effects should be included in RFI in order to get an accurate estimate of total warming impacts from aviation even though uncertainty remains about the precise

nature of AIC (CORE, 2011). Therefore, there has been great debate as to the exact RFI that should be used in measuring CO₂e emissions. The IPCC reports overall radiative forcing by aircraft (excluding that from changes in cirrus clouds) is a factor of 2 to 4 larger than the forcing by aircraft carbon dioxide alone (Penner, Lister, Griggs, Dokken, and McFarland, 1999). In 1992, the IPCC report estimated the average annual RFI to be 2.7, and this is the figure that is most commonly cited and used. In 2003, another prominent publication, EU FP5 research project TRADEOFF study, released an average RFI (excluding that from changes in cirrus clouds) of 1.9. The TRADEOFF study is now considered “the best-quantified estimate of radiative forcing index of aviation emissions” (Ross, 2009).

Another inconsistency among emission calculators, besides the RFI, is the emissions factor. The emission factor or coefficient is defined as “a unique value for scaling emissions to activity data in terms of a standard rate of emissions per unit of activity (EIA, 2011). The most accurate method to calculate the emissions factor for air travel is through fuel usage of a specific model of aircraft. However, because of the large variability of models, mileage, and fuel types it is not feasible to track each individual flight to the various emissions factor assigned to each model of aircraft. This would be especially difficult for large institutions. The most realistic method to calculate the emissions factor for air travel is based on air mileage. Unfortunately, this method incorporates many assumptions in order to create an emissions factor. Each calculator has its own method of calculating the emissions factor and adds to the difficulty of measuring the air travel emissions.

Although there have been many advances in the area of air travel emission calculations, an overall consistency is still lacking. There are countless different methodologies that make logical assumptions about how to calculate the same number. In order for the emission data to be relevant and useful there needs to be a unified method so that the data generated can be compared universally rather than just internally. Until that point is reached, best judgment should be used to choose the most relevant emissions calculations based on the available information.

Western Kentucky University's Air Travel Emissions Calculation Methodology

The first step in the process was to calculate miles traveled with in the year. The university's Air Travel Activity Report provided a large portion of the data needed to reasonably estimate the mileage. The Report provided the origin and destination airports for each trip that was authorized with payment by procurement card or authorized through employee travel reimbursement. Because the university's air travel is delegated to individual departments instead of centralized travel booking, the absolute amount of mileage must be deduced from available information. The Air Travel Activity Report is merely a portion of the university's total air travel. Currently there is not enough information to estimate the remaining portion of the university's total air travel. Therefore, all calculations are based on data retrieved from the Air Travel Activity Report. Although the data is incomplete, it provides the means to analyze a large portion of the data. In the future, the remaining portion can be estimated by using the mean miles traveled per flight to account for the missing data.

From the university's Air Travel Activity Report the mileage between airports was calculated using the Web Flyer Mile Marker Calculator. This calculator allowed the user to enter either the city or airport code and it then provided the approximate mileage between the two airports. The air mile distances were based on data provided by various outside sources to aid in air mileage estimation. Once the mileage was established, several footprint calculators, worksheets, and formulas were analyzed in order to determine an appropriate method to measure Western Kentucky University's greenhouse gas emissions. Numerous institutions have created tools that can assist individuals, families, businesses, and universities in quantifying their emissions. Several methods were examined and then narrowed down to three options that seemed most appropriate for WKU. The Bonneville Environmental Foundation Carbon Calculator, the Clean Air Cool Planet Worksheet: Emissions Based on Distance, and the EPA

Worksheet 3: Calculating Your Greenhouse Gas Emissions from Flights were then further researched and analyzed. Although, the exact emissions factors and radiative forcing indexes vary, the end results of the calculations are relatively close in comparison.

Bonneville Environmental Foundation

The Bonneville Environmental Foundation (BEF), a Portland, Oregon based nonprofit organization, focuses on the development and use of new renewable energy resources and restore watershed ecosystems. In 1999 the foundation began to expand their operations to include activities related to carbon footprints. Just a few years later in 2001 the foundation launched an online BEF Carbon Calculator. The BEF Carbon Calculator has the most transparent and descriptive methodologies of the three calculators. The website provided a succinct description of the effects of air travel as well as a detailed description of their calculations. (BEF, 2011). The chart below summarizes the precise factors used in calculating emissions based on air mileage per passenger and a description of the data is explained in more detail.

Bonneville Environmental Foundation						
Calculator						
	factor	8%				
Short	0.000164	0.043719	MTCO ₂ e/passenger mile	<	2,500	miles
Long	0.000179	0.057404	MTCO ₂ e/passenger mile	>	2,500	miles
RFI	2.00					
CO ₂ e= (miles * factor*RFI) + 8% factor						

The calculator provides the user the option to use broad estimates based on how many flights or a more specific estimate based on air mileage. For the air mileage calculation, the first step is to classify the flight as either short haul or long haul. Based on United States trends, the long haul flights are usually associated with larger sized aircraft. BEF made the assumption that the transition from small to larger sized air craft tends to be around 2,500 miles. This distinction is important because the gallons of fuel per hour, cruising speed, and passenger loads are different for each size. BEF used the UNECE Aircraft Inventory Guidebook and Manufacturer/Airline specs figures to calculate the number of gallons of fuel burned per passenger on the flight for small and large air craft. Next the BEF multiplied the emissions factor for the aircraft by the RFI to account for the additional strain air travel has on the environment due to the high altitude of the emissions. After consulting with the Climate Neutral Network, BEF decided to use an RFI of 2 in order to keep up with the latest research. Lastly, an additional 8% is added to account for the emissions associated with the upstream refining of jet fuel based on the Climate Neutral Network's analysis of air travel.

Clean Air Cool Planet

Clean Air-Cool Planet (CA-CP) is dedicated to finding and promoting solutions to global warming by establishing partnerships with companies, campuses, communities, and science centers to help reduce their carbon emissions. The organization has comprehensive outreach efforts that showcase practical climate solutions, propose and recommend the implementation, and assist users in measuring their carbon emissions. Since 2002, CA-CP has provided the Campus Carbon Calculator as a comprehensive and customizable solution to measuring and analyzing greenhouse gas emissions. It is a popular tool for tracking university's carbon footprints. (CA-CP, 2011). Western Kentucky University

currently utilizes the program to track a portion of its carbon emissions. “CA-CP’s Campus Carbon Calculator is the methodology followed by the majority of signatories to the American College and University Presidents’ Climate Commitment” (Duke, 2011). The chart below summarizes factors used in calculating emissions based on air mileage per passenger.

Clean Air - Cool Planet					
Campus Carbon Calculator					
Short	0.000290	MTCO ₂ e/passenger mile	<	280.86	miles
Medium	0.000200	MTCO ₂ e/passenger mile	=	S -- L	miles
Long	0.000180	MTCO ₂ e/passenger mile	>	994.19	miles
RFI	2.8				
CO ₂ e = [(miles) * factor]					

The figures for CA-CP are from an earlier version of the Worksheet: Emissions Based on Distance. This worksheet was the most transparent when compared to the recent updates that have been made on the CA-CP’s newest version of the Campus Carbon Calculator, Version 6.7. The new version uses imbedded formulas to calculate the overall emissions for each type of GHG individually. This complicated the process of tracking the emissions factor and the RFI for CO₂e emissions. In an effort to maintain consistency among the calculator comparisons, the earlier version of the worksheet was used in the calculations. Unfortunately, the reasoning behind the factors was not explained very well for example the classification of a short, medium, and long flight were not explained and the factors were not well sited. Hopefully, the new version can be further examined in order to better understand the calculation methodology.

Environmental Protection Agency

The Environmental Protection Agency (EPA) has a broad mission statement to “protect human health and the environment.” The organization has many subsets within the agency and its climate change programs and activities are an important part of the mission statement. The Climate Change Web site offers the public the most current and accurate information on the broad issue of climate change such as science, U.S. climate policy, greenhouse gas emissions, and health and environmental effects. EPA offers an online calculator for users to estimate their individual carbon footprint. There is a separate worksheet that is used to calculate carbon emissions caused by air craft. The chart below summarizes the precise factors used in calculating emissions based on air mileage per passenger and a description of the data is explained in more detail.

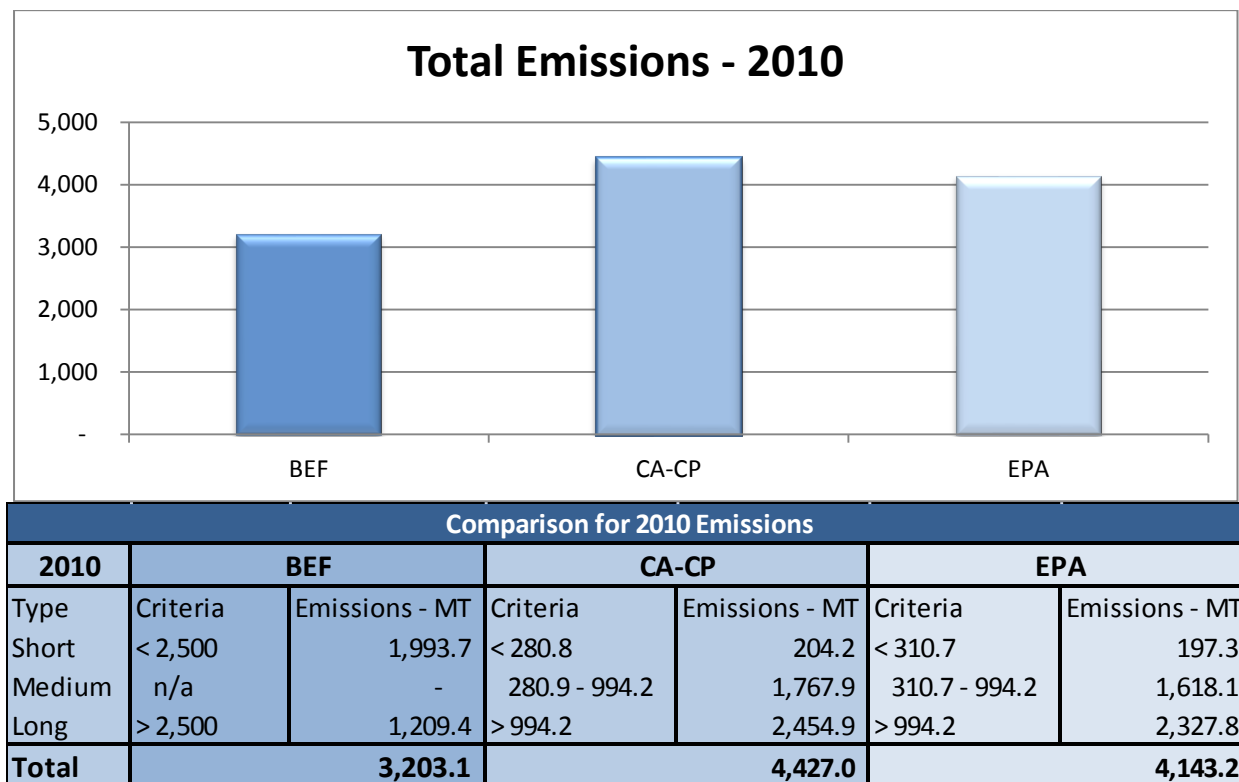
Environmental Protection Agency					
Calculator					
Short	0.000241	MTCO ₂ e/passenger mile	<	310.69	miles
Medium	0.000193	MTCO ₂ e/passenger mile	=	S -- L	miles
Long	0.000177	MTCO ₂ e/passenger mile	>	994.19	miles
RFI	2.7				
CO ₂ e = miles * factor * RFI					

The EPA Worksheet 3: Calculating Your Greenhouse Gas Emissions from Flights provides the emissions factors and briefly explains why a RFI is necessary in calculating the true effect of air travel.

The EPA cited the IPPC as its source for a RFI of 2.7. The worksheet clearly explains the formula used to calculate GHG emissions, but does not explain the reasoning behind the emissions factors. At the bottom of the worksheet the EPA list three sources that were consulted when developing the methodology. The most relevant source was the EPA Victoria; Greenhouse Inventory Management Plan 2006/07 which cited the GHG Protocol for the emission factors. The EPA Victoria applies the GHG Protocol default factor for short, medium, and long haul flights based on passenger distance, and assumes that domestic and trans-Tasman (New Zealand) flights are medium haul flights and all other international flights are long haul flights. The international data may not accurately reflect the emissions associated with predominately domestic flights.

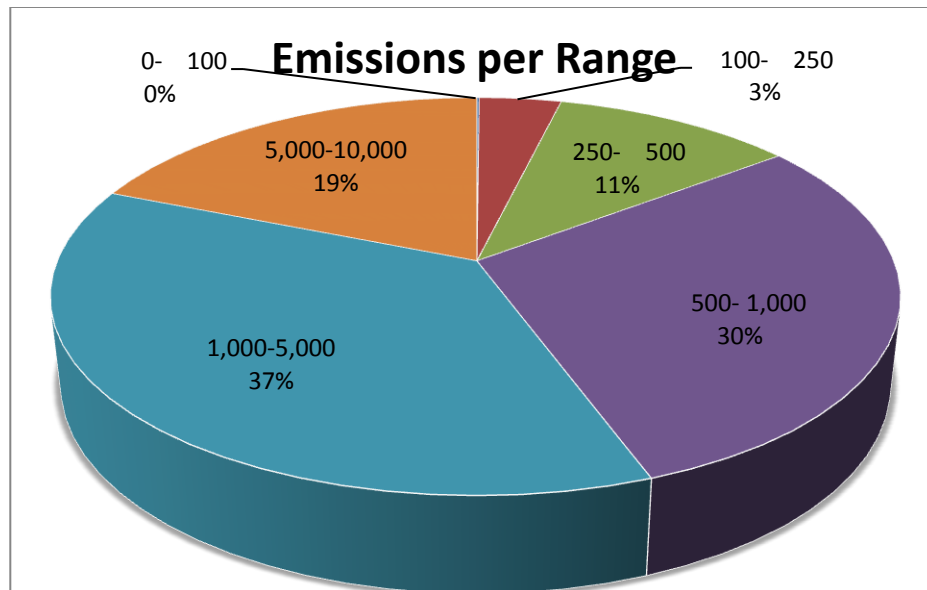
Western Kentucky University Results

The BEF Carbon Calculator method was the most appropriate for WKU because it is the most transparent of the three calculators. The logic behind the calculations suited WKU's needs to measure the emissions for long and short haul flights. The emission factors used on the BEF Calculator were deduced from national estimates, and the RFI of 2 is considered the most updated estimate of the index. The most unique characteristic of the calculator is the additional 8% added to the overall calculation to account for the emissions associated with the upstream refining of jet fuel. Using the BEF Carbon Calculator, the emissions for the shorter flights represent a larger portion of the emissions because the calculator attributes a larger portion of the emissions to take off and landing of the aircraft rather than idle time during the flight. Because of this assumption, the BEF Carbon Calculator has lower emissions for the longer flights. The graph below displays the total emissions measured in MTCO₂e per passenger mile and the chart provides the details of the emissions according to the distinction of short, medium, and long flights as determined by each calculator.



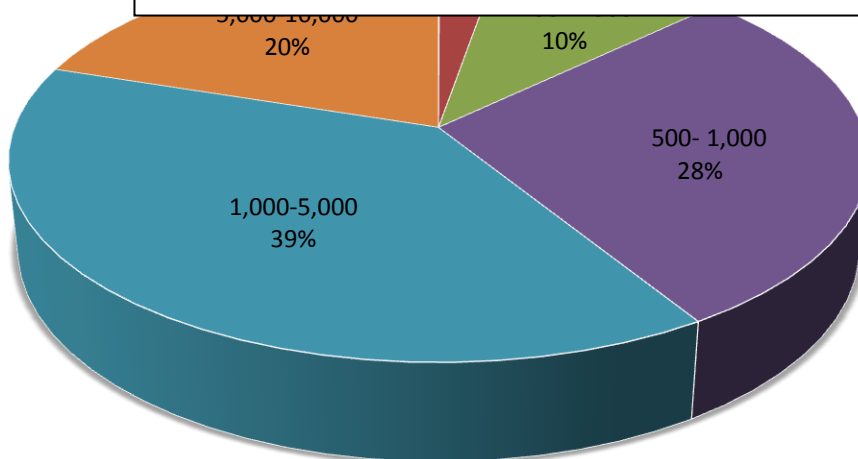
The BEF Carbon Calculator produced the lowest estimate of carbon equivalent emissions. The difference in the total emissions is partially caused by assumptions made by each calculator when determining the criteria for the length of the flight, the RFI index, and the emissions factors for each type of flight. The BEF criteria for the length of the flight are much different than the other two indexes because BEF made the assumption that the transition from small to larger sized air craft tends to be around 2,500 miles. The other two calculators did not specify the reasoning behind the criteria for the length of flights, but they have both chosen under roughly 300 miles as the distinction for short flights and approximately over 1,000 miles to represent long flights. The next difference is that the BEF has chosen an RFI of 2.0 while CA-CP used 2.8 and EPA uses 2.7. The difference in RFI is particularly significant because in all equations the emissions are calculated and then multiplied by the RFI. A high RFI is correlated with higher total emissions. The calculator with the highest RFI (CA-CP) has the highest amount of total emissions, and the calculator with the lowest RFI (BEF) has the lowest amount of total emissions. This may not always be the rule because the calculations are dependent on the emissions factor as well. Another interesting difference is the change in the emissions factors for long, medium, and short flights. The CA-CP and the EPA emissions factors decrease as the flight become longer while BEF emissions factors increase for the longer flight. The difference is caused by assumptions made by each calculator when determining the factors. A reasonable explanation for the difference is attempting to balance out the increased amount of fuel consumed by a larger air craft (which would increase the emission factor) with the increased passenger capacity (which would decrease the emissions factor). The variance in total emissions could also be due to the frequency and distance of the flights. The table below displays the number of flights, the total mileage, and the emissions associate with the following mileage ranges. The pie charts show the percentage for each of the categories listed in the table.

BEF Carbon Calculator - Emissions 2010			
Mileage Ranges	Emissions - MT	Mileage	# of Flights
0 - 100	3.32	3,707	48
100 - 250	118.56	218,856	1,066
250 - 500	371.66	842,230	2,167
500 - 1,000	923.47	2,345,654	3,482
1,000 - 5,000	1,178.68	3,217,134	1,533
5,000 - 10,000	607.42	1,651,690	257
Total	3,203.11	8,279,271	8,553



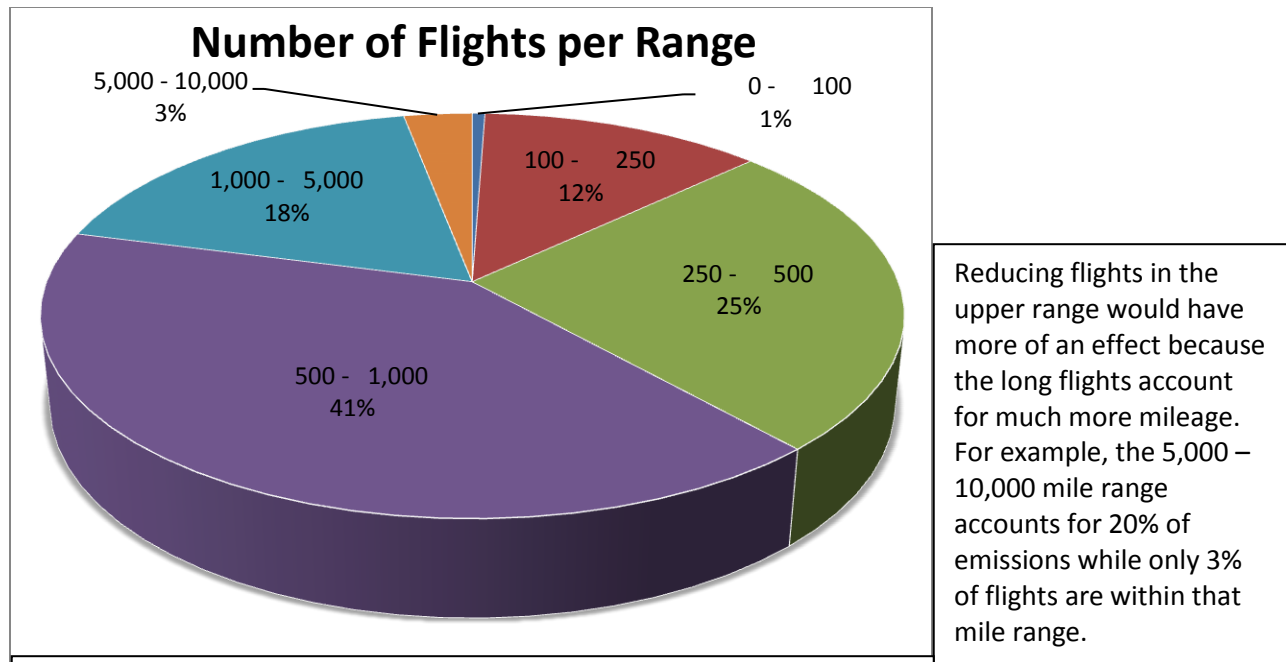
The Emissions per Range and Mileage per Range graphs are quite similar because the emissions are based on the mileage. There is a slight difference because of the additional 8% that is included in the formula for calculating the emissions which incorporates the number of flights.

ile range
about 13% of
s and
38% of the



flights. This range represents the flights that could possibly be eliminated through alternative transportation that produces less emissions.

As the mile ranges increase the mileage per range becomes larger than the number of flights. This is because the miles per flight are increasing and therefore account for more emissions because the equations are calculated per mile.



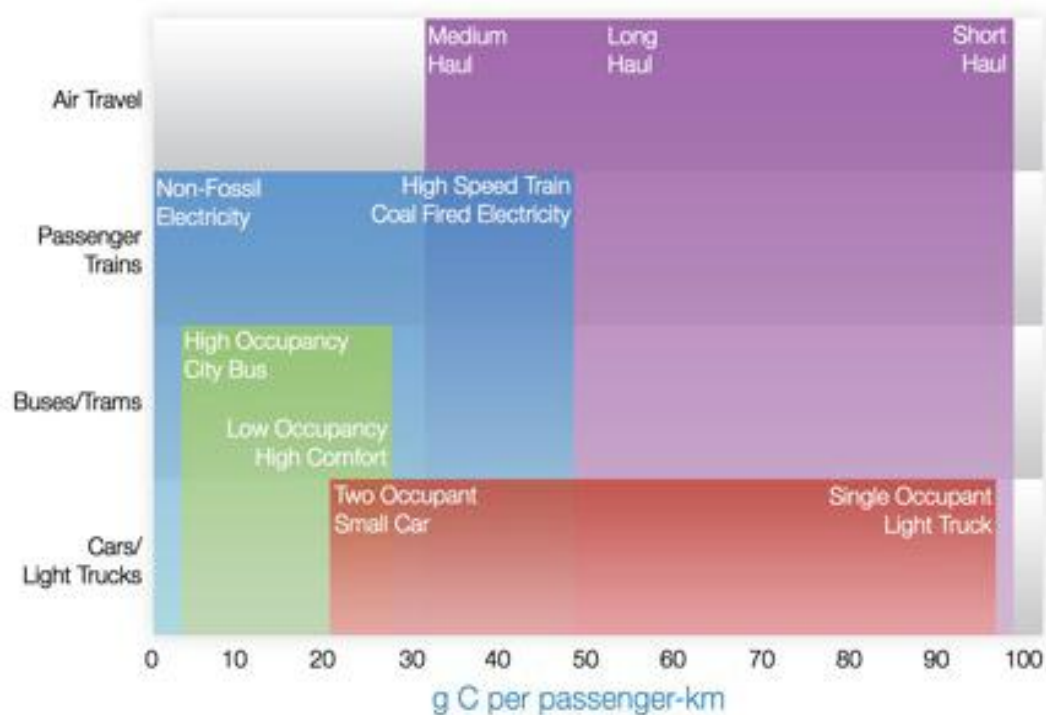
Alternatives to Air Travel

The most obvious alternative for air travel would be to simply stop flying, but this is not a feasible solution. Another option could be to drive to the desired location instead. There are other considerations that the traveler must be aware of when it comes to traveling. A car will still emit carbon, but there are some advantages to driving rather than flying. For example, a car emits carbon on the surface level of the Earth rather than directly into the upper atmosphere which is much more harmful (hence the need for the RFI index in calculating air travels). If there is more than one person traveling, the emission could be divided by the amount of passengers rather than multiplied as it would in air travel because the car emissions are calculated per car while the emissions are measured per passenger mile. Another benefit of driving is that the advances in technology related to fuel consumption. Hybrids and bio fuel cars are becoming more popular and also reducing the emissions associated with driving. One disadvantage to driving that cannot be overlooked is time. It is amazing how quickly one can fly across the country. For some trips the only option may be to fly, but for shorter distances it may be reasonable to drive instead. One must consider the location of the airports, transportation to the airport, the time it will take to go through security once inside the airport, the time it will take to check luggage and wait at baggage claims upon arrival, transportation subsequent to landing, and much more. For some shorter trips it could very well take less time to drive rather than fly. The charts below represent some common trips that could potentially be driven rather than flown.

BNA - MEM (Memphis International Airport)						
	Miles	Time	Emissions-BEF	# of Flights	Total Emissions	
Air	200	0.57	0.11 MT	104	11.39	MT
Land	220	3.67	0.07 MT		7.55	MT
Difference	20	3.10	0.04 MT	Reduce Emissions by 3.83 MT		
BNA - ATL (Hartsfield-Jackson Atlanta International Airport)						
	Miles	Time	Emissions-BEF	# of Flights	Total Emissions	
Air	214	0.61	0.11 MT	434	49.51	MT
Land	253	4.45	0.08 MT		36.22	MT
Difference	39	3.84	0.03 MT	Reduce Emissions by 13.29 MT		
BNA - CLT (Charlotte-Douglas International Airport)						
	Miles	Time	Emissions-BEF	# of Flights	Total Emissions	
Air	328	0.94	0.15 MT	144	15.76	MT
Land	396	6.65	0.13 MT		13.59	MT
Difference	68	5.71	0.02 MT	Reduce Emissions by 2.18 MT		

The common flights were chosen through a process of elimination. Each of these airports were selected because they had a frequency of over 50 flights, the mileage was less than 500 miles, and the time it would take to drive was under 7 hours. To remain consistent the distance it would take to get to the BNA airport has been ignored. There are also some uncertainties associated with the database information. It is unclear as to which flights serve as a connection and which flights were directly to the destination. Therefore, there is no way to calculate the full distance of some of the trips or to know how many people traveled together because each flights is considered independently.

The picture below depicts the range of Carbon that is emitted from various modes of transportation. Passenger trains and busses/trams are of the lowest carbon emitters depending on the type of fuel and the occupancy rate. The emissions for cars and aircraft vary depending on the type of model used, the number of passengers, and the distance of the trip.



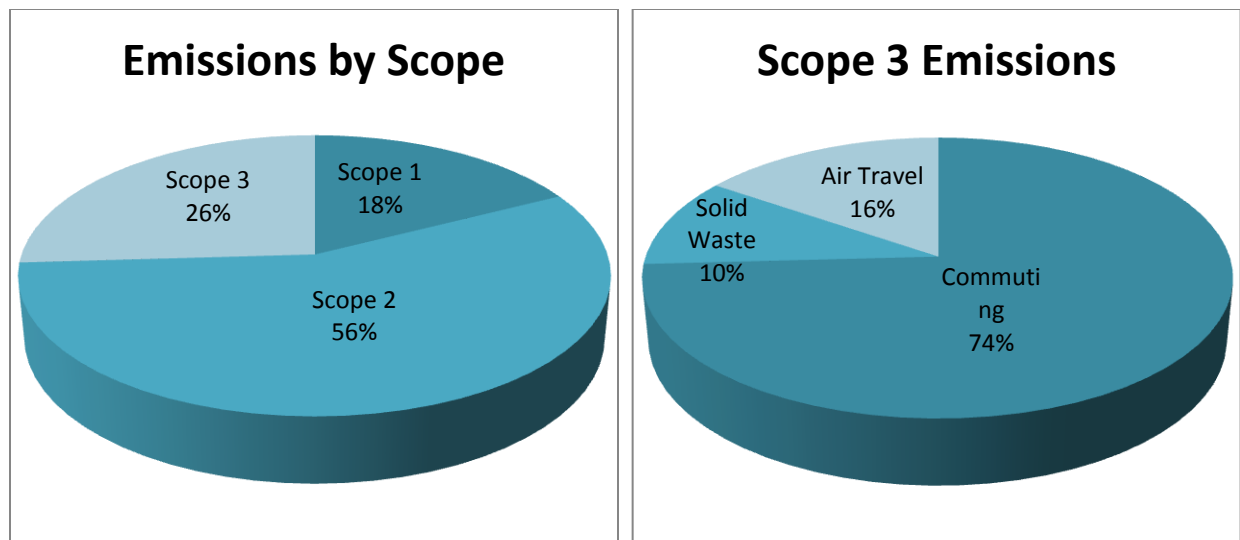
Carbon intensity of passenger transport (IPCC, 1999).

While there are many different options for traveling, the feasibility of employing those methods must also be considered. Time and simplicity are valuable to the university's employees and should be considered in the decision for travel.

WKU Carbon Footprint – GHG Emission Inventory

WKU has completed the university GHG emission inventory. The GHG inventory allows the university to study its carbon footprint, better learn which actions and choices make the most sense, and gain insight as to how to be more sustainable. The GHG inventory measures the university's main campus and WKU Farm emissions for Scope 1-3 sources. Scope 1 includes on-site combustion of fossil fuels, such as the coal and natural gas burned for heat and fuel used in vehicle motors. Scope 2 includes purchased electricity. Scope 3 includes faculty, staff and student commuting, emissions associated with solid waste and waste water treatment, and air travel emissions. (WKU Office of Sustainability, 2010).

The preliminary estimates for the campus carbon footprint are based on imperfect and limited data. The purpose of the inventory is to serve as a benchmarking tool rather than an exact figure. The pie charts below display the percentages of each scope as well as a breakdown of Scope 3 emissions.



Future Implications

There is still progress to be made. As previously stated, the Air Travel Activity Report is merely a portion of the university's total air travel. The remaining portion will need to be estimated and included in the total emissions so the calculations can provide a more encompassing estimate. All of the calculations above were based solely on data from the Air Travel Activity Report. Another area that still needs research is the CA-CP methodology. The CA-CP is utilized by the majority of signatories to the American College and University Presidents' Climate Commitment. If the methodology suited the needs of WKU it might be more beneficial to use the CA-CP Campus Carbon Calculator, Version 6.7 because it is commonly used by other universities. This would allow WKU to more accurately compare itself to other universities because of the unified methodology.

Work Cited

- BEF. "FAQs." Bonneville Environmental Foundation. Web. 10 June 2011. <<http://www.b-e-f.org/faqs/calc>>.
- CA-CP. "About CA-CP." Clean Air-Cool Planet. Web. 22 June 2011. <<http://www.cleanair-coolplanet.org/>>.
- CORE. "CORE: Aviation Contrails." Carbon Offset Research & Education (CORE). Web. 14 June 2011. <<http://www.co2offsetresearch.org/aviation/Contrails.html>>.
- Duke. "Sustainability : Measuring Up: A Comparison of Air Emissions Calculation Methodologies." Sustainability : Sustainable Duke. Web. 22 June 2011. <http://sustainability.duke.edu/carbon_offsets/Methodology.html>.
- EIA. "Voluntary of Greenhouse Gases Program - Glossary of Terms." Energy Information Administration. Web. 09 June 2011. <<http://www.eia.gov/oiaf/1605/whatis.html>>.
- EPA. "Emission Facts: Metrics for Expressing Greenhouse Gas Emissions: Carbon Equivalents and Carbon Dioxide Equivalents | US EPA." US Environmental Protection Agency. Web. 14 June 2011. <<http://www.epa.gov/oms/climate/420f05002.htm#carbon>>.
- EPA. "Glossary of Climate Change Terms | Climate Change | U.S. EPA." US Environmental Protection Agency. Web. 14 June 2011. <<http://www.epa.gov/climatechange/glossary.html>>.
- EPA. US Environmental Protection Agency. Web. 22 June 2011. <<http://www.epa.gov/>>.
- Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, 2007: Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Marian Koshland Science Museum. "Global Warming Facts and Our Future - Causes of Change – Amplifiers - Clouds." Marian Koshland Science Museum of the National Academy of Sciences. Web. 14 June 2011. <<http://www.koshland-science-museum.org/exhibitgcc/causes11.jsp>>.
- Maurice,, Lourdes, Curtis Holsclaw, Maryalice Locke, Ian Waitz, Stephen Lukachko, and Rick Miake-Lye. "Aviation and the Global Atmosphere: The State of the Science and Future Research Needs." U.S. Climate Change Science Program Workshop: "Climate Science in Support of Decision Making" Nov. 2005. Web. 9 June 2011. <http://www.climatechange.gov/workshop2005/posters/P-GC1.13_Maurice.pdf>.
- Penner, Joyce E., David H. Lister, David J. Griggs, David J. Dokken, and Mack McFarland. "Aviation and the Global Atmosphere." IPCC - Intergovernmental Panel on Climate Change. Cambridge University Press, 1999. Web. 09 June 2011. <<http://www.ipcc.ch/ipccreports/sres/aviation/index.php?idp=1>>.
- Ross, Davide. "GHG Emissions Resulting from Aircraft Travel." Carbon Planet. May 2009. Web. 20 June 2011. <http://www.carbonplanet.com/downloads/Flight_Calculator_Information_v9.2.pdf>.
- WKU Office of Sustainability, "2010 Sustainability Report." 2011. Sustainability Publications and Resources. Paper 6.