

More About this Life Cycle Inventory

Essentially, this life cycle inventory is a three-way comparison that examines the energy and resource requirements alongside the environmental impacts of three choices in reading materials. We call these three choices ‘scenarios’. Just to recap: In scenario #1, a reader buys an eBook edition of ‘Paradigm Progress’ online and receives it instantly as a digital download delivered over the internet to his or her computer. Scenario #2 sees a reader buy an equivalent hard cover edition – also online – but for delivery, the hard cover book is packaged in a corrugated box and is physically transported to the reader’s location via express shipping that includes air freight. Scenario #3 is essentially the same as scenario #2, except that instead of express shipping using air freight, delivery of the packaged hard cover book is made exclusively by truck. All three scenarios involve equivalent sized reading materials (with the eBook being an electronic file, while the hard cover books are concrete items common to bookshelves everywhere).

As our calculations demonstrate; a significant aspect of the energy requirements and airborne emissions for scenarios #2 and #3 arises from the physical transportation of these hard cover books to their delivery destination. Our findings show – as a general rule – that as the delivery distance increases, and also as the speed of delivery quickens; so too does the energy requirements and resulting emissions that are associated with making the delivery. This is because greater distances demand more fuel, of course, and faster deliveries inherently consume more fuel as well, because faster vehicles are more energy intensive.

To assess these logistical energy requirements and airborne emissions with the greatest accuracy we could manage, it was necessary to model fuel consumption and resulting emissions with great detail – the chief detail being a pair of precise locations marking the start and end of the delivery trip. This is a distinguishing characteristic of this life cycle inventory, as we have modelled for a very specific logistical flow that ends at the ‘Lebanon City Library’ (located at 404 Main Street, in Lebanon, Kansas, USA). Accordingly, deliveries to other locations will produce different inventories.

NOTE: Because this is a ‘cradle to gate’ life cycle inventory, we have only examined the production and delivery of these reading materials, but not their use nor their ultimate disposal, which would be called a ‘cradle to grave’ life cycle inventory.

Assessing “Soft” eBooks from DigiNatal Publishing

To make the comparison that is the focus of this life cycle inventory, we began by producing eBook editions of the Author’s work entitled ‘Paradigm Progress’; including ‘.epub’ and ‘.mobi’ editions (among others), which are the most popular open source file formats for eBooks. This helped us to establish the electronic file sizes of the resulting eBook editions, and gave us a basis for estimating the resource requirements and environmental impacts of delivering these eBooks as digital downloads transmitted over the internet. (It should be noted that producing dematerialized eBooks is essentially a zero-requirement and no-impact process, because electronic files are copied ad hoc as part of the internet transmission process, without any ‘upstream’ material requirements or ‘scrap’, nor the need for advance storage, maintenance or packaging. Therefore, nearly all of the resource requirements and environmental emissions are attributable to the process of delivering the eBooks, but not for actually producing them; very much unlike hardcopy books.)

To perform the calculations needed to assess scenario #1; we have relied on the research presented by Christopher L. Weber, Jonathan G. Koomey, and H. Scott Matthews; in their article entitled “The Energy and Climate Change Implications of Different Music Delivery Methods”, published in the ‘Journal of Industrial Ecology’ (2010, Yale University, Volume 14, Number 5). These researchers applied and/or established a number of statistics that informed our calculations, and we are very grateful to be able to draw on their work.

1. An internet data transfer energy intensity factor of 7 kWh per gigabyte, current as of 2008. The researchers note that this figure is decreasing by approximately 30% per year, or 50% every two years, owing to technological innovation and the installation of new computer equipment in data centres around the world. However, for want of specific corroborating evidence to support this assertion, we have applied the 2008 energy intensity factor of 7 kWh per gigabyte transferred, even though there is strong reason to believe that this overestimates the energy requirements of present-day data transfers over the internet. (Note that this over-estimation represents a bias against eBooks.)

2. The researchers assumed a United States average CO₂-equivalent emissions factor for grid-delivered electric power of 650 g/kWhr, which they also found to be the median value for global electric power production (which ranges between 300-900 g/kWhr). Accordingly, we have applied this US average/global median value throughout our calculations. Using this emissions factor makes sense, because of the way that data is transmitted across the internet, with a single file being divided into numerous ‘data packets’



that are routed in unpredictable fashion through data centres around the world, until they reach the destination web server, where they are recompiled into a single file and sent to the destination computer. For this reason, a single, global value is more useful than regionally-specific factors. Perhaps in future, when appropriate sets of meta data and the tools necessary to analyze them with rigour become available, this factor in our calculations can be improved.

3. The researchers also made the assumption that between 1 MB and 2 MB of data transfers are inherent to the process of online shopping and the purchase transaction. Accordingly, we have assumed that 2 MB of data transfers owing to ‘transaction processing’ are inherent to every electronic purchase of one of our eBooks (in scenario #1), as well as to the hardcopy editions that are bought and shipped in scenarios #2 and #3.

4. Weber, Koomey and Matthews also assumed that between 11 and 20 minutes were spent by purchasers to shop online. We have applied the high-end assumption of 20 minutes spent in this process, also across the board, for scenarios #1, #2 and #3.

5. Following the lead set by Weber, Koomey and Matthews, we further assumed that these 20 minutes of time spent shopping online, also entailed a combined energy requirement of some 200 watts of on-site energy for home computer use, lighting, heating and cooling of the room, and the network energy overhead for the transaction. This assumption is also on the high-end of the range considered by the researchers, who modelled for between 40-200 watts of energy; and we applied this energy requirement to all three scenarios examined in this life cycle inventory.

6. Weber, Koomey and Matthews also factored-in the energy requirement of 0.004 kWhr per minute allotted to the embodied manufacturing energy needed to build the computer used by the purchaser to execute the online purchase transaction. This value is based on an assumed lifetime of 3 years for the computer. Further assuming 20 minutes of time spent online, this means our analysis should include 0.08 kWhr of energy use allocation for the computer, per transaction, also for all three scenarios.

With this information, calculating the resource requirements and environmental emissions for scenario #1 becomes a simple matter of factoring the eBook file sizes against these figures, as appropriate. The results of these calculations are detailed in the following table:

Table 1: Scenario #1 - eBook Specifications, Online Purchase and Digital Download Power Requirements, and Carbon Dioxide Emissions							
eBook Edition	Electronic File Size	Transaction Data	Internet Power Usage	On-Site Power Usage	Computer Mfg Energy Req't	TOTAL POWER	Carbon Dioxide Emissions
.pdf	0.99 MB	2 MB	0.02093 kWhr	0.2 kWhr	0.08 kWhr	0.30093 kWhr	0.196 kg
.epub	0.389 MB	2 MB	0.01672 kWhr	0.2 kWhr	0.08 kWhr	0.29672 kWhr	0.193 kg
.mobi	0.449 MB	2 MB	0.01714 kWhr	0.2 kWhr	0.08 kWhr	0.29714 kWhr	0.193 kg
Average ►	0.609 MB		0.018 kWhr			0.298 kWhr	0.194 kg

Assessing “Hardcopy” Books

One of the eBook editions we always produce is in the ‘Portable Document Format’ with the file extension ‘.pdf’. This is a widely used file format originally developed by Adobe Systems® in 1993. What distinguishes PDF files from other electronic formats is that they encapsulate a complete description of a fixed-layout flat document, including the text, fonts, graphics, and other information needed to display it. In so doing, we can establish the page dimensions and page counts that would be needed to produce any hardcopy edition of the same literary work. Indeed, PDFs are the industry standard format for book printers producing complex layouts. (Other eBook formats have ‘scalable’ font sizes, to allow readers to alter or ‘vary’ how the work is paginated. Effectively, PDFs ‘fix’ pagination, thereby giving us a basis for estimating the resource requirements and environmental impacts of hardcopy analogues, as we have done for scenario #2 and #3.

After establishing page dimensions and counts, we augmented this descriptive information with additional, reasonable book-designing options to define the complete set of specifications for a comparative hardcopy book. (If ‘Paradigm Progress’ were available as a hardcopy edition, we would simply use its specifications to inform our analysis.) In our LCI model we account for such things as paper weights, quantities utilized and scrapped (considering the stock sizes of the basis sheets and the printing ‘signature’ and resulting ‘cross’ (cuttings) needed to produce the book); as well as material types and contents, and the relative percentages of

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recycled and virgin source fibres. We did this for every component of the hardcopy book. For hard cover editions, this includes the cover jacket, the hard covers themselves, the paper ‘inner’ and ‘outer’ facings that are glued to the hard covers to make them presentable, and the ‘text guts’ that comprise the bulk, printed pages of the book. Soft cover editions are similar, but with a lighter cover that wraps-around the book, and without the ‘inner’ and ‘outer’ facings or the cover jacket. The cover stock specified for soft cover editions is also much lighter than for hard cover editions, naturally.

We should note that whatever scrap we have accounted for in our estimates, arises only from the cropping of basis sheets to achieve the page sizes specified as explained above. So-called ‘make-ready’ scrap and scrap arising from the proofing process are not included. Much more significantly, we should also note that many of the hardcopy books printed in the world are never sold or read by anyone. They are scrapped without ever having been opened by a single living soul. For many print runs, upwards of seventy percent of the books printed meet this sad and wasteful fate. If we were to account for all of this scrap, and apportion it appropriately to the hardcopy books in our LCI model, the comparison vis a vis eBooks would reflect very, very poorly on hardcopy books. Our decision to exclude all of these sources of scrap, and to focus only on the ‘production scrap’ inherent to the single hardcopy that is directly in our focus, is yet another instance of us being more than fair in our comparison. We did, however, include 0.8 grams CO₂-eq to account for the emissions inherent to trucking the production scrap for the hardcopy book to a (fictitious) recycling facility located 100 kilometres away.

To be clear, we should also note that our estimates of the resource requirements and resulting emissions for hardcopy books, whether they are hard or soft covered; does not include consideration of the energy required by the book printer to actually manufacture the book, nor any consideration of the inks used for printing, nor any adhesives that were used. In future, these considerations may be added to our LCI model, in order to produce an even more complete life cycle inventory. In sum, the results of all these calculations are detailed in the following table:

Table 2: Scenarios #2 and #3 - Hardcopy Book Material Specifications and Usage							
Element	Material Type	Material Utilization	Gross Material Usage	Scrap	Net Material Shipped	Virgin Material	Recycled Material
Cover Jacket	Coated Freesheet	16.5" x 9.25" x 1 pg @ 111 GSM (w/ 30% recycled & 70% virgin mat'l)	17.0 grams	6.1 grams	10.9 grams	12 grams	5 grams
Cover	Uncoated Unbleached Kraft Paperboard	6.25" x 9.25" x 2 pg @ 352 GSM (w/ 90% recycled & 10% virgin mat'l)	39.3 grams	13.1 grams	26.2 grams	4 grams	35 grams
Cover Outer Facing	Coated Freesheet	14" x 10" x 1 pg @ 47 GSM (w/ 30% recycled & 70% virgin mat'l)	9.7 grams	5.4 grams	4.3 grams	7 grams	3 grams
Cover Inner Facing	Uncoated Freesheet	12.38" x 9" x 2 pg @ 96 GSM (w/ 30% recycled & 70% virgin mat'l)	14.7 grams	0.9 grams	13.8 grams	10 grams	4 grams
Main Text Guts	Uncoated Freesheet	6.19" x 9" x 160 pg @ 104 GSM (w/ 40% recycled & 60% virgin mat'l)	635.0 grams	39.2 grams	595.8 grams	381 grams	254 grams
Shipping Box	Unbleached Corrugated	13" x 20" x 1 pc (w/ 100% recycled & 0% virgin mat'l)	52.8 grams	Not Included	54.6 grams *w/ glue	0 grams	53 grams

At the end of this step, all of these specifications were then factored against data from the ‘Environmental Paper Network Paper Calculator’ (available online at www.papercalculator.org). The results of these calculations are depicted in the following tables:



Element	Wood Use	Net Energy	Purchased Energy
Cover Jacket	37 grams	157 watt-hours	124 watt-hours
Cover	14 grams	260 watt-hours	218 watt-hours
Cover Outer Facing	21 grams	89 watt-hours	71 watt-hours
Cover Inner Facing	39 grams	139 watt-hours	104 watt-hours
Main Text Guts	1.4 kgs	5.8 kilowatt-hours	4.5 kilowatt-hours
Shipping Box	0.0000 grams	335 watt-hours	330 watt-hours
TOTALS	1.5 kgs	6.7 kilowatt-hours	5.3 kilowatt-hours

Element	Solid Waste	Wastewater	Biochemical Oxygen Demand	Suspended Solids	Chemical Oxygen Demand
Cover Jacket	17 grams	1.2 litres	0.06 grams	0.1 grams	0.2 grams
Cover	11 grams	482 millilitres	0.09 grams	0.1 grams	0.07 grams
Cover Outer Facing	10 grams	678 millilitres	0.04 grams	0.07 grams	0.09 grams
Cover Inner Facing	13 grams	1.1 litres	0.07 grams	0.1 grams	0.2 grams
Main Text Guts	515 grams	46.3 litres	3 grams	5 grams	7 grams
Shipping Box	3 grams	442 millilitres	0.1 grams	0.1 grams	0.06 grams
TOTALS	568 grams	50.3 litres	3 grams	5 grams	8 grams

Element	Greenhouse Gases	Sulphur Oxides	Nitrogen Oxides	Particulates	Hazardous Air Pollutants	Volatile Organic Compounds	Total Reduced Sulphur
Cover Jacket	46 grams	0.2 grams	0.08 grams	0.04 grams	0.02 grams	0.02 grams	0.003 grams
Cover	60 grams	0.4 grams	0.1 grams	0.05 grams	0.02 grams	0.03 grams	0.001 grams
Cover Outer Facing	26 grams	0.1 grams	0.04 grams	0.02 grams	0.01 grams	0.01 grams	0.002 grams
Cover Inner Facing	39 grams	0.2 grams	0.07 grams	0.04 grams	0.02 grams	0.02 grams	0.003 grams
Main Text Guts	1.6 kgs	8 grams	3 grams	2 grams	0.6 grams	0.8 grams	0.1 grams
Shipping Box	69 grams	0.6 grams	0.2 grams	0.07 grams	0.05 grams	0.04 grams	0.003 grams
TOTALS	0	10 grams	3 grams	2 grams	0.8 grams	0.9 grams	0.1 grams

About the Corrugated Shipping Package

After we fully specified the hardcopy edition as explained above; we computed the specifications for a corrugated box that would be suitable to ship it. We took great care not to over-specify this corrugated box, being certain not to make it any bigger or thicker or sturdier than absolutely necessary. To be sure, the corrugated box we have modelled may not be commercially available, and likely no such box would ever be used by any book distributor to ship any comparable book. However, we have taken this approach in order to minimize the contribution of the shipping box to the overall footprint of the hardcopy books in our comparison. We have



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done this, even though we can model – with unparalleled precision – for virtually any corrugated shipping carton; and even though there is a great likelihood that a hardcopy book distributor would probably use a larger box in real life. (Please see note #6 for the complete specification of the shipping box we have modelled.) As with the hardcopy book, we have factored the resultant material usage statistics for the corrugated shipping carton against the energy requirements and emissions factors drawn from the ‘Environmental Paper Network Paper Calculator’ (available online at www.papercalculator.org).

Hardcopy Logistics

In the specification-setting exercise for the hard cover analogue of our eBook and its shipping package, described above; we established the weight of the package that would be shipped to the reader located at the ‘Lebanon City Library’. This package weight informed all of our logistical calculations, which were variations on the following four equations: FIRST: ‘Package Weight’ x ‘Shipping Distance’ = ‘Workload’. SECOND: ‘Workload’ x ‘Vehicle-Specific Energy Intensity Factor’ = ‘Energy Requirement’. THIRD: ‘Energy Requirement’ / ‘Regional/Fuel-specific Net Calorific Value’ = ‘Fuel-Type Quantity’. AND FOURTH: ‘Fuel-Type Quantity’ x ‘Various Emissions Factors’ = ‘Resultant Emissions’. Combined, these four equations are known as the ‘fuel use’ method for calculating emissions, and this method is considered the most accurate for calculating emissions attributable to the transportation of freight. Let’s examine each of these variables with more detail, for the sake of clarity and to understand more about what sets this life cycle inventory apart from others.

Package Weight: This is the weight of the finished hardcopy analogue of our eBook entitled ‘Paradigm Progress’, plus the corrugated shipping package it would be delivered in, as detailed above. At present, we have excluded any other items that might ordinarily be included in such a delivery, such as an invoice, bill of lading, export/import documents, receipt, label, coupon or promotional materials or any kind of adhesive or packing tape. Moreover, any scrap that would have been produced in the making of the hardcopy book is also not on-board with this package. It is important to note that for every component of this packaged hardcopy book, our estimations of its weight are exact, insofar as the ‘mill weight’ of the materials still holds true at the time of delivery. What this means is that the so-called mill weight reflects the moisture content of the materials at the time they left their respective paper mills of original manufacture (typically 4-5% by weight). However, the printing process and or storage in moist environments or transit through humid environments – even the seasons or temperature changes – may cause the actual weight to vary from the mill weights we have relied upon to calculate our estimates. For the time being, we have chosen to ignore these factors, for want of a way to accurately model them, and have assumed that the mill weight of all these materials is appropriate for our current purposes. For the purpose of our logistics calculations, the package weight we have used is 0.71 kg (1.56 Lbs.).

Shipping Distance: To determine a shipping distance, it was necessary to define a starting location, a delivery destination and a route between them (which for multi-modal shipping, involves multiple logistical ‘legs’ which may not be covered by the same vehicle or even type of vehicle). As a matter of course, we already had a delivery destination in mind (actually, many more than one, but we want to consider them one at a time). What we really needed was a starting location. To pick one, we decided that for our purposes, it was best to set a ‘fake’ starting location, which we have called the ‘Fictitious Printing Plant’. This is where we have modelled that all of the material components are merged into the hardcopy book and its shipping package.

We picked a (non-existent) street address as the starting location for this simulated delivery of our spurious hardcopy book, for the sake of making a comparison to our eBooks. In this same spirit, we have depicted a fake building at this location in the ‘.kml’ file viewable using ‘Google Earth’ software. If you have ‘Google Earth’ installed on your computer – even the free version – double-clicking on this ‘.kml’ file will display all of the points of interest and the delivery routes that we have modelled for, up to the present point in time. (We continually add destinations and delivery routes to this file, which you can find on the DigiNatal Publishing webpage for ‘Paradigm Progress’ at <http://www.diginatal.com/paradigmprogress>. By surveying the latest release of this file, you can quickly review the location-specific summary reports of this ‘DC-LCI’ (distributed and comparative, life cycle inventory), where you can even click-through to see the full poster-reports and the detailed notes to accompany them. Simply click on the book icons that depict the cover of ‘Paradigm Progress’ and wait for the API to load the summary report (or scroll to the bottom of the pop-up bubble and click-through to find more information).

In our calculations, we have used kilometres exclusively, even though we have sometimes expressed results in miles, or for aviation or navigation, in nautical miles.

Workload: This is the product of the package weight (expressed in metric tonnes), multiplied by the shipping distance for each leg (expressed in kilometres), which results in a ‘workload’ that is defined in units of work known as ‘metric-tonne kilometres’. One metric-tonne kilometre is the workload that is required to move one metric tonne a distance of one kilometre.



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Vehicle-Specific Energy Intensity Factor: These are a series of factors that we have compiled, the bulk of which we have drawn from research conducted under the auspices of the 'International Energy Agency' (www.iea.org), which detail, on a regional basis, the modal energy intensities of different forms of freight transportation, including light and heavy duty trucks, rail, aviation and navigation. The use of this regional and time-sensitive data set, with its application to different vehicle types and vintages, is one of the nuances that makes our emissions estimates more accurate than can typically be computed with most online calculators, or even the guidelines provided by the 'Greenhouse Gas Protocol Initiative'. This value is expressed in 'megajoules per metric-tonne kilometre'.

Energy Requirement: By factoring the 'Workload' implied for a specific logistical leg, against the chosen 'Vehicle-Specific Energy Intensity Factor', we can determine the 'Energy Requirement' that is appropriate for the given region, considering where the logistical leg is modelled to take place, which further considers the vehicle fleet in operation in that region (by vehicle vintage). This value is expressed in kilojoules.

Regional/Fuel-specific Net Calorific Value: All fuels are not alike, and from region-to-region around the world, not even the same types of fuel are perfectly alike, owing to different sources and differing production practices at various petroleum refineries. To account for this variation around the world, we have again drawn on data from the 'International Energy Agency' to use 'Net Calorific Values' that are specific to different regions – which is yet another nuance that makes our emissions estimates more accurate than can typically be computed with most online calculators. This 'Net Calorific Value' (NCV) is a measure of the energy potential of a given weight of fuel, and is expressed in units of 'kilojoules per kilogram'.

Fuel-Type Quantity: By dividing the 'Energy Requirement' by the 'Regional/Fuel-specific NCV', we can at last determine the quantity of the specific type of fuel that is required to move the package from one point to another, all of the above things properly considered. In our calculations, this value is expressed as kilograms of a specific type of fuel.

Emissions Factors: We have taken great care to select and properly use the most appropriate emissions factors for all of our logistical emissions calculations. Most of our emissions factors have been drawn from the guidelines and the 'Emissions Factor Database' published by the 'Intergovernmental Panel on Climate Change' (www.ipcc.ch); the world's leading authority and the chief scientific body concerned with these matters. Our high level of care is mandatory, because the combustion of a certain amount of a given fuel, in different vehicles, will produce different emissions profiles. In no case is this more critical than for aviation. As with all of the emissions factors we have used for every mode of *freight* transport, the emissions factors for air freight are expressed in terms of grams of a gas emitted for a given weight of fuel combusted (grams of gas per kg of fuel used). The unique challenge posed by calculating emissions for freight logistics involving airplanes, is that the available emissions factors are all applicable for cruise-level flight only, and do not consider the emissions that are produced during the landing and takeoff (LTO) cycle, which can be considerable, especially for short-distance flights.

In our considered opinion, this represents a significant deficiency with emissions inventories prepared for air freight, particularly in the North American context, where we are heavily reliant on aviation for express shipping that might typically be used to deliver hardcopy books bought online, as we have modelled in scenario #2 and #3. In order to address this deficiency, we have devised a novel approach to estimate air freight emissions arising during the LTO cycle, in order to include these significant emissions in our life cycle inventory.

To explain our novel approach, first we must explain that by and large; aircraft emissions are dependent on the quantity of fuel that is combusted. The exception to this rule pertains to nitrogen oxides emissions (also referred to as NOx), which vary depending on a number of factors that are variable across the flight profile. The causes of this variation include; power output levels (that are highest during take-off and climb); engine operating temperatures (that are lower during ground taxiing), and; ambient oxygen levels (that are lowest at cruise-level altitudes). Moreover, for any particular aircraft, these are further variable due to such factors as engine design and power output, and of course, the aerodynamic properties of different models of aircraft. This explains why most aircraft emissions can be calculated as constants, related to fuel consumption, and also why nitrogen oxides emissions must be estimated with aircraft-specific emissions factors.

Accordingly, we drew on data published by the Intergovernmental Panel on Climate Change (IPCC), through their 'Emission Factor Data Base' (EFDB – available online at <http://www.ipcc-nggip.iges.or.jp/EFDB/main.php>), in order to calculate carbon dioxide (CO₂), carbon monoxide (CO), methane (CH₄), nitrous oxide (N₂O), non-methane volatile organic compounds (NMVOC), and sulphur oxides (SO₂+SO₃) emissions. To estimate nitrogen oxides (NO+NO₂) emissions, we drew on data published in the '2006 IPCC Guidelines for National Greenhouse Gas Inventories', which details aircraft-specific, fuel-consumption based emissions factors for nitrogen oxides emissions.



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However, as has already been explained: All of these emissions factors are pertinent to cruise-level flight operations only (referred to as ‘climb-cruise-descent’, or CCD), and we wanted to also include emissions that arise during the landing-and-takeoff (LTO) cycle. This was deemed important for two reasons. First, because data has shown that these emissions are significant. Second, because the significance of these emissions is increased with the number of landings-and-takeoffs; such that over a given distance, an aircraft flying direct and non-stop, would produce fewer emission than the same aircraft making stopovers en route. We wanted our heuristic DC-LCI model to reflect this, and so we had to model emissions that arise during the LTO cycle.

To do this, we examined the primary data set that is at the root of all such aviation emissions factors in use in the world today. This data set is published by the European Environment Agency (EEA), as part of their ‘European Monitoring and Environment Program’ (EMEP). The name of this data set is ‘CORINAIR’, and it is itself a compilation of a state-of-the-art series of emissions modelling and directly observed data points. This CORINAIR data set informs both the IPCC emissions factors and those promulgated by the United Kingdom’s DEFRA, as well as the United States EPA and the ‘Greenhouse Gas Protocol Initiative’. It is a very detailed data set that tallies fuel consumption data with resultant emissions, on a whole-aircraft basis, for different mission distance thresholds, and different aspects of the flight profile.

For our purposes, we grouped the different aspects of the flight profile into two categories; being CCD operations and LTO operations. We then computed the ratio of fuel use and emissions between LTO operations and CCD operations, for each aircraft and each mission distance threshold. Once we had established these statistics, it became a simple matter of applying the correct ratio to the cruise-level emissions factors we drew from the IPCC, in order to extrapolate LTO fuel requirements and resulting emissions.

It should be noted that EEA scientists have not established data for every aircraft in operation in the world today. But thankfully, they have established the comparability of different aircraft in their data set to aircraft that are not in their data set. This has allowed us to use representative CORINAIR “proxy” data, in order to model fuel consumption and emissions for all of the “designated” aircraft that we have modelled. This is how we have modelled fuel requirements and resulting emissions stemming from the landing-and-takeoff cycle – by factoring the IPCC emissions factors for cruise-level flight operations, by the ratios we computed from the CORINAIR data set.

For the delivery of the hardcopy book modelled in scenario #2, there were three (3) different flights en route to the terminal delivery destination at the Lebanon City Library. The table below details the CORINAIR data that we drew upon and the ratios they helped us to establish. (NB: These figures are rounded, whereas the original data set is not rounded).



Aviation Routing Information	Designated Aircraft and CORINAIR Proxy Aircraft	Mission Distance Information	CORINAIR Fuel Consumption Data	CORINAIR Carbon Monoxide Data	CORINAIR Nitrogen Oxides Data	CORINAIR Hydrocarbons Data
Leg Leg 2 of 5 from: Lester B. Pearson International Airport, IATA Airport Code YYZ, Toronto, Canada; to: Detroit Metropolitan Wayne County Airport, IATA Airport Code DTW, Detroit, USA.	Designated Aircraft: Bombardier CRJ-100ER (CORINAIR Proxy Aircraft: Embraer 110P2A).	375.4 km (therefore drawing on CORINAIR data for flights up to 463 km)	48.9 kg during LTO / 224.7 kg during CCD = An LTO/CCD ratio of 0.21762, for fuel used by this aircraft over this distance.	371.4 kg during LTO / 869.2 kg during CCD = An LTO/CCD ratio of 0.42729, for carbon monoxide emitted by this aircraft over this distance.	0.3 kg during LTO / 1.3 kg during CCD = An LTO/CCD ratio of 0.21085, for nitrogen oxides emitted by this aircraft over this distance.	24.4 kg during LTO / 48.6 kg during CCD = An LTO/CCD ratio of 0.50206, for hydrocarbons emitted by this aircraft over this distance.
Leg Leg 3 of 5 from: Detroit Metropolitan Wayne County Airport, IATA Airport Code DTW, Detroit, USA; to: Chicago Midway International Airport, IATA Airport Code MDW, Chicago, USA.	Designated Aircraft: Embraer ERJ145 (CORINAIR Proxy Aircraft: Embraer 110P2A).	400.0 km (therefore drawing on CORINAIR data for flights up to 463 km)	48.9 kg during LTO / 224.7 kg during CCD = An LTO/CCD ratio of 0.21762, for fuel used by this aircraft over this distance.	371.4 kg during LTO / 869.2 kg during CCD = An LTO/CCD ratio of 0.42729, for carbon monoxide emitted by this aircraft over this distance.	0.3 kg during LTO / 1.3 kg during CCD = An LTO/CCD ratio of 0.21085, for nitrogen oxides emitted by this aircraft over this distance.	24.4 kg during LTO / 48.6 kg during CCD = An LTO/CCD ratio of 0.50206, for hydrocarbons emitted by this aircraft over this distance.
Leg Leg 4 of 5 from: Chicago Midway International Airport, IATA Airport Code MDW, Chicago, USA; to: Kansas City International Airport, IATA Airport Code MCI, Kansas City, USA.	Designated Aircraft: Boeing 737-700 (CORINAIR Proxy Aircraft: B737 400).	709.1 km (therefore drawing on CORINAIR data for flights up to 926 km)	825.4 kg during LTO / 2787.4 kg during CCD = An LTO/CCD ratio of 0.29611, for fuel used by this aircraft over this distance.	11830.9 kg during LTO / 5694.6 kg during CCD = An LTO/CCD ratio of 2.07757, for carbon monoxide emitted by this aircraft over this distance.	8.3 kg during LTO / 28.6 kg during CCD = An LTO/CCD ratio of 0.28827, for nitrogen oxides emitted by this aircraft over this distance.	666.8 kg during LTO / 329.1 kg during CCD = An LTO/CCD ratio of 2.02637, for hydrocarbons emitted by this aircraft over this distance.

To our knowledge, no other published life cycle inventory or online emissions calculator or even the ‘calculation tools’ promoted by the ‘Greenhouse Gas Protocol Initiative’ (www.ghgprotocol.org) have addressed this deficiency with the same or more substantial rigour as have we. (Please, if you know otherwise, or if you recognize any error or problem with our life cycle inventory, do not hesitate to let us know by contacting us through either of our websites, www.synerlux.com or www.diginatal.com. We would be very grateful for your corrections and suggestions for improvement.)

Calculation Results

Resultant Emissions: By applying the emissions factors to the fuel use statistics, we derive the ‘Resultant Emissions’. In the present iteration of our LCI model, these include, as is scientifically appropriate; carbon dioxide (CO₂), carbon monoxide (CO), methane (CH₄), nitrogen oxides (NO+NO₂), nitrous oxide (N₂O), non-methane volatile organic compounds (NMVOCs – a class of chemicals that all contain carbon atoms), and sulphur oxides (SO₂+SO₃). These results demanded yet another level of calculation aimed at correcting the ‘carbon balance’ of the emissions profile established for each specific logistical leg.

You see; the emission factors for carbon dioxide assume that 100% of the carbon content of the fuel used was combusted or ‘oxidized’. However, when any fuel is burned in an engine, the exhaust gases invariably contain partially-burned constituents that have not been fully oxidized. This is because engines constrain the oxygen supply as the fuel is put to work to generate power, and is especially the case when engines operate in the ‘thin’ atmosphere of higher altitudes, as do airplanes at cruise levels, or



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conversely, when jet engines are operated at lower power levels while on the ground (as this entails a lower operating temperature at which combustion is also less than complete). Road vehicles operating under load (as they all do) also produce partially combusted exhaust emissions. For this reason, it is necessary to quantify the carbon content of the other carbonaceous gases and subtract the carbon dioxide equivalent from the primary carbon dioxide emissions that were calculated with the use of the 'primary' CO₂ emissions factor. Doing this for carbon monoxide and methane is a relatively straightforward affair. However, to include the carbon dioxide equivalent emissions that are classified under the NMVOC umbrella, we must first identify the constituent 'species' of carbonaceous emissions that make up the NMVOCs emitted. (Not every life cycle analysis takes this additional step, which we have taken in the interest of precision.)

At present, we have relied upon two 'organic gas species profiles' to do this (and we intend to add more profiles in the near future). For aviation emissions of NMVOCs; we have relied upon the profile published in "Recommended Best Practice for Quantifying Speciated Organic Gas Emissions from Aircraft Equipped with Turbofan, Turbojet, and Turboprop Engines, Version 1.0" by the 'Assessment and Standards Division Office of Transportation and Air Quality', U.S. Environmental Protection Agency, and 'AEE-300 - Emissions Division' at the 'Office of Environment and Energy', 'Federal Aviation Administration' (in the United States). (Publication ID: EPA-420-R-09-901 May 2009). For trucking emissions of NMVOCs; we have relied upon the data published by the United States Environmental Protection Agency in their "Speciate Data Browser, version 4.2" as profile #2563 - 'Roadway - Vehicle Exhaust Emissions - Raleigh' (with the added assumption that the 50.55% unidentified portion, by weight, is actually 'isobutene/1-butene' (CAS 106-98-9), which has an approximately average hydrogen/carbon ratio as seen among the identified speciate constituents in this profile). Accordingly, the isobutene/1-butene emissions identified for trucking logistics should be considered as suspect, even while they may arguably be considered suitable for our purposes of correcting the carbon balance of our emissions profiles. This profile #2563 is available online at <http://cfpub.epa.gov/si/speciate/index.cfm>. By applying the 'mass fractions' identified in these two organic gas speciate profiles, we were able to calculate the carbon dioxide equivalent emissions that we needed to subtract from the emission factor-derived quantities of carbon dioxide, in order to bring our emissions profile into stoichiometric balance (thereby avoiding the error of double-counting carbonaceous emissions). The final results of these calculations can be found in these 'Supplementary Notes' as indicated below:

Refer to NOTE #10 regarding logistical leg '1', which details NMVOC emissions including: 0.144 mg of ethylene; 0.133 mg of toluene; 0.119 mg of isopentane (2-methylbutane); 0.114 mg of acetylene; 0.107 mg of ethylbenzene; 0.0894 mg of m & p-xylene; 0.0652 mg of benzene; 0.0569 mg of n-pentane; 0.0507 mg of propylene; 0.0367 mg of ethane; 0.0353 mg of n-butane; 0.0285 mg of o-xylene; 0.0178 mg of propane; and 1.02 mg of unidentified (assumed isobutene/1-butene).

Refer to NOTE #26 regarding logistical leg '2', which details NMVOC emissions including: 7.97 mg of ethylene; 7.53 mg of C-10 paraffins; 6.34 mg of formaldehyde; 3.01 mg of C-10 olefins (modeled as trans-3,trans-6-decadiene); 3.01 mg of decanal; 2.34 mg of propylene; 2.20 mg of acetaldehyde; 2.03 mg of acetylene; 1.50 mg of 2-dodecenal; 1.26 mg of acrolein; 0.936 mg of glyoxal; 0.930 mg of methanol; 0.904 mg of isobutene/1-butene; 0.869 mg of 1,3-butadiene; 0.866 mg of benzene; 0.774 mg of methylglyoxal; 0.532 mg of crotonaldehyde; 0.400 mg of 1-pentene; 0.379 mg of 1-hexene; 0.375 mg of propionaldehyde; 0.374 mg of phenol; 0.338 mg of c4-benzene + c3-aroald; 0.331 mg of toluene; 0.279 mg of naphthalene; 0.276 mg of n-tridecane; 0.268 mg of ethane; 0.242 mg of benzaldehyde; 0.238 mg of n-dodecane; 0.229 mg of n-undecane; 0.226 mg of 1-heptene; 0.221 mg of methacrolein; 0.214 mg of n-tetradecane; 0.210 mg of 2-methylpentane; 0.190 mg of acetone; 0.185 mg of trans-2-pentene; 0.180 mg of 1,2,4-trimethylbenzene; 0.167 mg of c5-benzene + c4-aroald; 0.165 mg of n-decane; 0.159 mg of styrene; 0.143 mg of m-tolualdehyde; 0.142 mg of cis-2-pentene; 0.142 mg of 1-octene; 0.127 mg of 1-methyl naphthalene; 0.127 mg of 1-nonene; 0.126 mg of valeraldehyde; 0.118 mg of o-tolualdehyde; 0.108 mg of cis-2-butene; 0.106 mg of 2-methyl-naphthalene; 0.102 mg of n-pentane; 0.096 mg of c14-alkane (modeled as N-tetradecane); 0.095 mg of 1-decene; 0.095 mg of 2-methyl-2-butene; 0.091 mg of c15-alkane (modeled as N-pentadecane); 0.090 mg of ethylbenzene; 0.089 mg of n-pentadecane; 0.086 mg of o-xylene; 0.079 mg of m-ethyltoluene; 0.075 mg of c16-alkane (modeled as N-hexadecane); 0.073 mg of m-xylene; 0.073 mg of p-xylene; 0.072 mg of 2-methyl-1-butene; 0.061 mg of butyraldehyde; 0.058 mg of 3-methyl-1-butene; 0.055 mg of 1,2,3-trimethylbenzene; 0.046 mg of 2,6-dimethylnaphthalene; 0.040 mg of propane; 0.036 mg of 4-methyl-1-pentene; 0.033 mg of o-ethyltoluene; 0.033 mg of p-ethyltoluene; 0.033 mg of n-heptane; 0.032 mg of n-nonane; 0.032 mg of n-octane; 0.028 mg of 1,3,5-trimethylbenzene; 0.027 mg of n-propylbenzene; 0.025 mg of n-hexadecane; 0.025 mg of p-tolualdehyde; 0.018 mg of 2-methyl-1-pentene; 0.016 mg of isovaleraldehyde; 0.015 mg of trans-2-hexene; 0.005 mg of n-heptadecane; 0.002 mg of isopropylbenzene; and 0.001 mg of c18-alkane (modeled as N-octadecane).

Refer to NOTE #57 regarding logistical leg '3', which details NMVOC emissions including: 8.49 mg of ethylene; 8.02 mg of C-10 paraffins; 6.76 mg of formaldehyde; 3.21 mg of C-10 olefins (modeled as trans-3,trans-6-decadiene); 3.21 mg of decanal; 2.49 mg of propylene; 2.35 mg of acetaldehyde; 2.16 mg of acetylene; 1.60 mg of 2-dodecenal; 1.34 mg of acrolein; 0.997 mg of glyoxal; 0.991 mg of methanol; 0.963 mg of isobutene/1-butene; 0.926 mg of 1,3-butadiene; 0.923 mg of benzene; 0.825 mg of methylglyoxal; 0.567 mg of crotonaldehyde; 0.426 mg of 1-pentene; 0.404 mg of 1-hexene; 0.399 mg of propionaldehyde; 0.399 mg

of phenol; 0.360 mg of c4-benzene + c3-aroald; 0.352 mg of toluene; 0.297 mg of naphthalene; 0.294 mg of n-tridecane; 0.286 mg of ethane; 0.258 mg of benzaldehyde; 0.254 mg of n-dodecane; 0.244 mg of n-undecane; 0.240 mg of 1-heptene; 0.236 mg of methacrolein; 0.228 mg of n-tetradecane; 0.224 mg of 2-methylpentane; 0.203 mg of acetone; 0.197 mg of trans-2-pentene; 0.192 mg of 1,2,4-trimethylbenzene; 0.178 mg of c5-benzene + c4-aroald; 0.176 mg of n-decane; 0.170 mg of styrene; 0.153 mg of m-tolualdehyde; 0.152 mg of cis-2-pentene; 0.152 mg of 1-octene; 0.136 mg of 1-methyl naphthalene; 0.135 mg of 1-nonene; 0.134 mg of valeraldehyde; 0.126 mg of o-tolualdehyde; 0.115 mg of cis-2-butene; 0.113 mg of 2-methyl-naphthalene; 0.109 mg of n-pentane; 0.102 mg of c14-alkane (modeled as N-tetradecane); 0.102 mg of 1-decene; 0.102 mg of 2-methyl-2-butene; 0.097 mg of c15-alkane (modeled as N-pentadecane); 0.096 mg of ethylbenzene; 0.095 mg of n-pentadecane; 0.091 mg of o-xylene; 0.085 mg of m-ethyltoluene; 0.080 mg of c16-alkane (modeled as N-hexadecane); 0.077 mg of m-xylene; 0.077 mg of p-xylene; 0.077 mg of 2-methyl-1-butene; 0.065 mg of butyraldehyde; 0.061 mg of 3-methyl-1-butene; 0.058 mg of 1,2,3-trimethylbenzene; 0.049 mg of 2,6-dimethylnaphthalene; 0.043 mg of propane; 0.038 mg of 4-methyl-1-pentene; 0.036 mg of o-ethyltoluene; 0.035 mg of p-ethyltoluene; 0.035 mg of n-heptane; 0.034 mg of n-nonane; 0.034 mg of n-octane; 0.030 mg of 1,3,5-trimethylbenzene; 0.029 mg of n-propylbenzene; 0.027 mg of n-hexadecane; 0.026 mg of p-tolualdehyde; 0.019 mg of 2-methyl-1-pentene; 0.018 mg of isovaleraldehyde; 0.016 mg of trans-2-hexene; 0.005 mg of n-heptadecane; 0.002 mg of isopropylbenzene; and 0.001 mg of c18-alkane (modeled as N-octadecane).

Refer to NOTE #88 regarding logistical leg '4', which details NMVOC emissions including: 30.3 mg of ethylene; 28.6 mg of C-10 paraffins; 24.1 mg of formaldehyde; 11.5 mg of C-10 olefins (modeled as trans-3,trans-6-decadiene); 11.5 mg of decanal; 8.89 mg of propylene; 8.38 mg of acetaldehyde; 7.72 mg of acetylene; 5.73 mg of 2-dodecenal; 4.80 mg of acrolein; 3.56 mg of glyoxal; 3.54 mg of methanol; 3.44 mg of isobutene/1-butene; 3.31 mg of 1,3-butadiene; 3.30 mg of benzene; 2.95 mg of methylglyoxal; 2.03 mg of crotonaldehyde; 1.52 mg of 1-pentene; 1.44 mg of 1-hexene; 1.43 mg of propionaldehyde; 1.42 mg of phenol; 1.29 mg of c4-benzene + c3-aroald; 1.26 mg of toluene; 1.06 mg of naphthalene; 1.05 mg of n-tridecane; 1.02 mg of ethane; 0.922 mg of benzaldehyde; 0.906 mg of n-dodecane; 0.871 mg of n-undecane; 0.859 mg of 1-heptene; 0.841 mg of methacrolein; 0.816 mg of n-tetradecane; 0.800 mg of 2-methylpentane; 0.724 mg of acetone; 0.704 mg of trans-2-pentene; 0.686 mg of 1,2,4-trimethylbenzene; 0.635 mg of c5-benzene + c4-aroald; 0.627 mg of n-decane; 0.606 mg of styrene; 0.545 mg of m-tolualdehyde; 0.541 mg of cis-2-pentene; 0.541 mg of 1-octene; 0.484 mg of 1-methyl naphthalene; 0.482 mg of 1-nonene; 0.480 mg of valeraldehyde; 0.451 mg of o-tolualdehyde; 0.412 mg of cis-2-butene; 0.404 mg of 2-methyl-naphthalene; 0.388 mg of n-pentane; 0.365 mg of c14-alkane (modeled as N-tetradecane); 0.363 mg of 1-decene; 0.363 mg of 2-methyl-2-butene; 0.347 mg of c15-alkane (modeled as N-pentadecane); 0.341 mg of ethylbenzene; 0.339 mg of n-pentadecane; 0.325 mg of o-xylene; 0.302 mg of m-ethyltoluene; 0.286 mg of c16-alkane (modeled as N-hexadecane); 0.276 mg of m-xylene; 0.276 mg of p-xylene; 0.275 mg of 2-methyl-1-butene; 0.233 mg of butyraldehyde; 0.220 mg of 3-methyl-1-butene; 0.208 mg of 1,2,3-trimethylbenzene; 0.176 mg of 2,6-dimethylnaphthalene; 0.153 mg of propane; 0.135 mg of 4-methyl-1-pentene; 0.127 mg of o-ethyltoluene; 0.125 mg of p-ethyltoluene; 0.125 mg of n-heptane; 0.122 mg of n-nonane; 0.122 mg of n-octane; 0.106 mg of 1,3,5-trimethylbenzene; 0.104 mg of n-propylbenzene; 0.096 mg of n-hexadecane; 0.094 mg of p-tolualdehyde; 0.067 mg of 2-methyl-1-pentene; 0.063 mg of isovaleraldehyde; 0.059 mg of trans-2-hexene; 0.018 mg of n-heptadecane; 0.006 mg of isopropylbenzene; and 0.004 mg of c18-alkane (modeled as N-octadecane).

Refer to NOTE #119 regarding logistical leg '5', which details NMVOC emissions including: 1.73 mg of ethylene; 1.59 mg of toluene; 1.42 mg of isopentane (2-methylbutane); 1.37 mg of acetylene; 1.29 mg of ethylbenzene; 1.07 mg of m & p-xylene; 0.781 mg of benzene; 0.682 mg of n-pentane; 0.607 mg of propylene; 0.440 mg of ethane; 0.423 mg of n-butane; 0.341 mg of o-xylene; 0.213 mg of propane; and 12.2 mg of unidentified (assumed isobutene/1-butene).

Refer to NOTE #135 regarding the 'All Road' delivery, details NMVOC emissions including: 0.144 mg of ethylene; 0.133 mg of toluene; 0.119 mg of isopentane (2-methylbutane); 0.114 mg of acetylene; 0.107 mg of ethylbenzene; 0.0894 mg of m & p-xylene; 0.0652 mg of benzene; 0.0569 mg of n-pentane; 0.0507 mg of propylene; 0.0367 mg of ethane; 0.0353 mg of n-butane; 0.0285 mg of o-xylene; 0.0178 mg of propane; and 1.02 mg of unidentified (assumed isobutene/1-butene).

Reference and Calculation Notes

The traditional book that we have used for the sake of comparison as our 'hardcopy analogue' is fictitious. It is a hard cover edition with the following specifications.

NOTE #1: There is a cover jacket made of offset paper stock. Each cover jacket has a finished size measuring 16.5" x 9.25" (41.9 cm x 23.5 cm), and we account for one such cover jacket per book. We have modelled that four cover jackets are made from each 'basis sheet' measuring 25" x 38" (63.5 cm x 96.5 cm). This cover jacket has a basis weight of '75 lbs.' and is made with 30%



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recycled fibre and 70% virgin material. This means that the 'Gross Material Utilization' for this cover jacket is 17.0 grams, with 6.1 grams of that being scrap material and 10.9 grams being incorporated into the book and shipped to the purchaser. Based on the material specifications, and on the data provided by the 'Environmental Paper Network Paper Calculator', this 'cover jacket' has the following composition: Virgin Pulp Enhanced EECF (Bleached Kraft) = 28%; Virgin Pulp Elemental Chlorine Free (Bleached Kraft) = 42%; Recycled Office Paper = 30%. Altogether, this means that for the cover jacket of this book (scrap included), the following resource requirements arise; 37 grams of wood use; 157 watt-hours of 'net energy' with 124 watt-hours of that being 'purchased electricity'. Also, approximately 1.2 litres of waste water is generated, which would contain 0.1 grams of 'suspended solids', resulting in a 'biochemical oxygen demand' of 0.06 grams and a 'chemical oxygen demand' of 0.2 grams. Additionally, 17 grams of solid wastes, destined for landfill, would be generated. A number of airborne emissions are also produced in the process of making the coated freesheet used in the cover jacket for this book, including; 46 grams of carbon dioxide equivalent greenhouse gases; 0.08 grams of nitrogen oxides; 0.2 grams of sulphur oxide, and 0.02 grams of 'volatile organic compounds'; 0.003 grams of 'total reduced sulphur'; 0.04 grams of airborne particulates and 0.02 grams of scheduled 'hazardous air pollutants'.

NOTE #2: There are covers made of cover stock. Each cover has a finished size measuring 6.25" x 9.25" (15.9 cm x 23.5 cm), and we account for two such covers per book. We have modelled that six covers are made from each 'basis sheet' measuring 20" x 26" (50.8 cm x 66 cm). These covers have a basis weight of '130 lbs.' and are made with 90% recycled fibre and 10% virgin material. This means that the 'Gross Material Utilization' for this cover is 39.3 grams, with 13.1 grams of that being scrap material and 26.2 grams being incorporated into the book and shipped to the purchaser. Based on the material specifications, and on the data provided by the 'Environmental Paper Network Paper Calculator', this 'cover' has the following composition: Kraft Unbleached = 10%; Recycled Corrugated Containers = 90%. Altogether, this means that for the cover of this book (scrap included), the following resource requirements arise; 14 grams of wood use; 260 watt-hours of 'net energy' with 218 watt-hours of that being 'purchased electricity'. Also, approximately 482 millilitres of waste water is generated, which would contain 0.1 grams of 'suspended solids', resulting in a 'biochemical oxygen demand' of 0.09 grams and a 'chemical oxygen demand' of 0.07 grams. Additionally, 11 grams of solid wastes, destined for landfill, would be generated. A number of airborne emissions are also produced in the process of making the uncoated unbleached kraft paperboard used in the cover for this book, including; 60 grams of carbon dioxide equivalent greenhouse gases; 0.1 grams of nitrogen oxides; 0.4 grams of sulphur oxide, and 0.03 grams of 'volatile organic compounds'; 0.001 grams of 'total reduced sulphur'; 0.05 grams of airborne particulates and 0.02 grams of scheduled 'hazardous air pollutants'.

NOTE #3: There is a cover outer facing made of offset paper stock. Each cover outer facing has a finished size measuring 14" x 10" (35.6 cm x 25.4 cm), and we account for one such cover outer facing per book. We have modelled that three cover outer facings are made from each 'basis sheet' measuring 25" x 38" (63.5 cm x 96.5 cm). This cover outer facing has a basis weight of '32 lbs.' and is made with 30% recycled fibre and 70% virgin material. This means that the 'Gross Material Utilization' for this cover outer facing is 9.7 grams, with 5.4 grams of that being scrap material and 4.3 grams being incorporated into the book and shipped to the purchaser. Based on the material specifications, and on the data provided by the 'Environmental Paper Network Paper Calculator', this 'cover outer facing' has the following composition: Virgin Pulp Enhanced EECF (Bleached Kraft) = 28%; Virgin Pulp Elemental Chlorine Free (Bleached Kraft) = 42%; Recycled Office Paper = 30%. Altogether, this means that for the cover outer facing of this book (scrap included), the following resource requirements arise; 21 grams of wood use; 89 watt-hours of 'net energy' with 71 watt-hours of that being 'purchased electricity'. Also, approximately 678 millilitres of waste water is generated, which would contain 0.07 grams of 'suspended solids', resulting in a 'biochemical oxygen demand' of 0.04 grams and a 'chemical oxygen demand' of 0.09 grams. Additionally, 10 grams of solid wastes, destined for landfill, would be generated. A number of airborne emissions are also produced in the process of making the coated freesheet used in the cover outer facing for this book, including; 26 grams of carbon dioxide equivalent greenhouse gases; 0.04 grams of nitrogen oxides; 0.1 grams of sulphur oxide, and 0.01 grams of 'volatile organic compounds'; 0.002 grams of 'total reduced sulphur'; 0.02 grams of airborne particulates and 0.01 grams of scheduled 'hazardous air pollutants'.

NOTE #4: There are cover inner facings made of offset paper stock. Each cover inner facing has a finished size measuring 12.38" x 9" (31.4 cm x 22.9 cm), and we account for two such cover inner facings per book. We have modelled that eight cover inner facings are made from each 'basis sheet' measuring 25" x 38" (63.5 cm x 96.5 cm). These cover inner facings have a basis weight of '65 lbs.' and are made with 30% recycled fibre and 70% virgin material. This means that the 'Gross Material Utilization' for this cover inner facing is 14.7 grams, with 0.9 grams of that being scrap material and 13.8 grams being incorporated into the book and shipped to the purchaser. Based on the material specifications, and on the data provided by the 'Environmental Paper Network Paper Calculator', this 'cover inner facing' has the following composition: Virgin Pulp Enhanced EECF (Bleached Kraft) = 28%; Virgin Pulp Elemental Chlorine Free (Bleached Kraft) = 42%; Recycled Office Paper = 30%. Altogether, this means that for the cover inner facing of this book (scrap included), the following resource requirements arise; 39 grams of wood use; 139 watt-hours of 'net energy' with 104 watt-hours of that being 'purchased electricity'. Also, approximately 1.1 litres of waste water is generated, which would contain 0.1 grams of 'suspended solids', resulting in a 'biochemical oxygen demand' of 0.07 grams and a 'chemical oxygen demand' of 0.2 grams. Additionally, 13 grams of solid wastes, destined for landfill, would be generated. A number of



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airborne emissions are also produced in the process of making the uncoated freesheet used in the cover inner facing for this book, including; 39 grams of carbon dioxide equivalent greenhouse gases; 0.07 grams of nitrogen oxides; 0.2 grams of sulphur oxide, and 0.02 grams of 'volatile organic compounds'; 0.003 grams of 'total reduced sulphur'; 0.04 grams of airborne particulates and 0.02 grams of scheduled 'hazardous air pollutants'.

NOTE #5: Then there are the main text guts made of offset paper stock. Each page has a finished size measuring 6.19" x 9" (15.7 cm x 22.9 cm), and we account for one-hundred and sixty such pages per book. We have modelled that sixteen pages can be made from each 'basis sheet' measuring 25" x 38" (63.5 cm x 96.5 cm). These main text guts have a basis weight of '70 lbs.' and are made with 40% recycled fibre and 60% virgin material. This means that the 'Gross Material Utilization' for this main text guts is 635.0 grams, with 39.2 grams of that being scrap material and 595.8 grams being incorporated into the book and shipped to the purchaser. Based on the material specifications, and on the data provided by the 'Environmental Paper Network Paper Calculator', this 'main text gut' has the following composition: Virgin Pulp Enhanced EECF (Bleached Kraft) = 24%; Virgin Pulp Elemental Chlorine Free (Bleached Kraft) = 36%; Recycled Office Paper = 40%. Altogether, this means that for the main text guts of this book (scrap included), the following resource requirements arise; 1.4 kgs of wood use; 5.8 kilowatt-hours of 'net energy' with 4.5 kilowatt-hours of that being 'purchased electricity'. Also, approximately 46.3 litres of waste water is generated, which would contain 5 grams of 'suspended solids', resulting in a 'biochemical oxygen demand' of 3 grams and a 'chemical oxygen demand' of 7 grams. Additionally, 515 grams of solid wastes, destined for landfill, would be generated. A number of airborne emissions are also produced in the process of making the uncoated freesheet used in the main text guts for this book, including; 1.6 kgs of carbon dioxide equivalent greenhouse gases; 3 grams of nitrogen oxides; 8 grams of sulphur oxide, and 0.8 grams of 'volatile organic compounds'; 0.1 grams of 'total reduced sulphur'; 2 grams of airborne particulates and 0.6 grams of scheduled 'hazardous air pollutants'.

NOTE #6: Lastly, there is the shipping box which is made of corrugating linerboard and fluting medium stocks. When cut-open and laid flat, each box measures approximately 13" x 20" (33 cm x 50.8 cm). This shipping box has a specification of 22/16/20-C. (Note: The figures before the dash denote the basis weights of the materials used in the corrugated wall(s), measured in lbs. per 1000 square feet; and the letters (and slashes) after the dash denote the wall size(s); as per industry practice.) We have assumed that all of these materials are of the same grade, consisting of 100% recycled fibre and 0% virgin material. This means that the 'Gross Forest-Source Material Utilization' for this shipping box is 52.8 grams (without scrap, which was not considered in our analysis), but with a functional weight of 54.6 grams owing to the glue used to hold the corrugating linerboard and fluting together. Based on the material specifications, and on the data provided by the 'Environmental Paper Network Paper Calculator', this 'shipping box' has the following composition: Recycled Corrugated Containers = 100%. Altogether, this means that for the shipping box of this book, the following resource requirements arise; 0.0000 grams of wood use; 335 watt-hours of 'net energy' with 330 watt-hours of that being 'purchased electricity'. Also, approximately 442 millilitres of waste water is generated, which would contain 0.1 grams of 'suspended solids', resulting in a 'biochemical oxygen demand' of 0.1 grams and a 'chemical oxygen demand' of 0.06 grams. Additionally, 3 grams of solid wastes, destined for landfill, would be generated. A number of airborne emissions are also produced in the process of making the unbleached corrugated used in the shipping box for this book, including; 69 grams of carbon dioxide equivalent greenhouse gases; 0.2 grams of nitrogen oxides; 0.6 grams of sulphur oxide, and 0.04 grams of 'volatile organic compounds'; 0.003 grams of 'total reduced sulphur'; 0.07 grams of airborne particulates and 0.05 grams of scheduled 'hazardous air pollutants'.

NOTE #7: Delivery Leg 1 of 5 from: Fictitious Printing Plant @ 11 Havenbrook Boulevard, Toronto, Ontario, Canada (M2J 1A5); to: Vista Cargo Centre - Pearson International Airport @ 6500 Silver Dart Drive, Mississauga, Ontario, Canada (L5P 1B1). This involves the transport of a 0.71 kg (1.56 Lb.) hard cover book (corrugated packaging included), a distance of 26.9 km (16.7 miles), establishing a 'workload' for this leg of 0.0190 metric-tonne kilometres. After factoring for the energy requirements of the 'Heavy-Duty Truck' we modelled for, the need for 30 kilojoules of energy is established, which is the fuel equivalent of 0.00071 kg of diesel oil (assuming an NCV of 42,600 KJ/kg). By applying the '2006 IPCC Guidelines for National Greenhouse Gas Inventories'; but using an even more precise method than the one suggested there; we calculated our 'base carbon dioxide emissions' using a CO2 intensity factor of 74 mg CO2 per kilojoule of fuel combusted (at 100% oxidation). We also drew on a select panel of emissions factors to model other emissions, including; carbon monoxide (CO), methane (CH4), nitrogen oxides (NO+NO2), nitrous oxide (N2O), and non-methane volatile organic compounds (NMVOCs). Because the CO, CH4 and NMVOCs all contain carbon, we then reduced our 'base CO2 estimate' to bring all of our emissions estimates into 'stoichiometric balance'.

NOTE #8: This truck-borne 'on road' leg for the delivery of the 0.71 kg (1.56 Lb.) hard cover book (corrugated packaging included); with delivery from 'Fictitious Printing Plant' at 11 Havenbrook Boulevard in Toronto, Ontario, Canada, -to- 'Vista Cargo Centre - Pearson International Airport' at 6500 Silver Dart Drive in Mississauga, Ontario, Canada; travelled a distance of 26.9 km (16.7 miles). It was carried on a heavy-duty truck fuelled with diesel oil and equipped with advanced control emissions abatement technology. The fuel was Diesel Oil of the IEA 2010 North American Default standard, having a 'net calorific value' of 42,600 KJ/kg.

... as delivered to Lebanon, Kansas, USA.

NOTE #9: The combustion of this quantity of this fuel in this truck operating under these conditions, will result in the following airborne emissions; 0.0022 kg of carbon dioxide; 0.000010 kg of carbon monoxide; 0.0000001 kg of methane; 0.000008 kg of nitrogen oxides (NO+NO₂); 0.000000 kg of nitrous oxide (N₂O); and 0.000002 kg of non-methane volatile organic compounds (NMVOCs).

NOTE #10: With reliance on research performed by the 'Environmental Protection Agency' in the United States; we can estimate the organic gas constituents that make up the NMVOC emissions, including: 0.144 mg of ethylene; 0.133 mg of toluene; 0.119 mg of isopentane (2-methylbutane); 0.114 mg of acetylene; 0.107 mg of ethylbenzene; 0.0894 mg of m & p-xylene; 0.0652 mg of benzene; 0.0569 mg of n-pentane; 0.0507 mg of propylene; 0.0367 mg of ethane; 0.0353 mg of n-butane; 0.0285 mg of o-xylene; 0.0178 mg of propane; and 1.02 mg of unidentified (assumed isobutene/1-butene).

NOTE #11: By applying the 'Organic Gas' speciate profile published through the US EPA's "Speciate Data Browser, Version 4.2" (Profile #2563 - 'Roadway - Vehicle Exhaust Emissions - Raleigh' (with the added assumption that the 50.55% unidentified portion, by weight, is actually 'isobutene/1-butene' (CAS 106-98-9), which has an approximately average hydrogen/carbon ratio as seen among the identified speciate constituents in this profile); we were able to perform a 'carbon mass balance' calculation to ensure that no 'double counting' entered our estimates. At their foundations, our estimates are based on the following data points; for carbon dioxide we drew upon IPCC Emission Factor ID #19026 which establishes a rate of emissions of 3172.31 g/kg fuel (Diesel Oil) burned in a Heavy-Duty Truck; for carbon monoxide we drew upon IPCC Emission Factor ID #19020 which establishes a rate of emissions of 14.01 g/kg fuel (Diesel Oil) burned in a Heavy-Duty Truck; for methane we drew upon IPCC Emission Factor ID #19014 which establishes a rate of emissions of 0.14 g/kg fuel (Diesel Oil) burned in a Heavy-Duty Truck; for nitrogen oxides (no+no₂) we drew upon IPCC Emission Factor ID #19011 which establishes a rate of emissions of 11.32 g/kg fuel (Diesel Oil) burned in a Heavy-Duty Truck; for nitrous oxide we drew upon IPCC Emission Factor ID #19023 which establishes a rate of emissions of 0.08 g/kg fuel (Diesel Oil) burned in a Heavy-Duty Truck; for non methane volatile organic compounds we drew upon IPCC Emission Factor ID #19017 which establishes a rate of emissions of 2.78 g/kg fuel (Diesel Oil) burned in a Heavy-Duty Truck. (NB: For factors expressed as a range, we modelled the 'median'.)

NOTE #12: To calculate fuel requirements, a number of factors were considered. First was the weight of the 0.71 kg (1.56 Lb.) hard cover book (including corrugated packaging), and the fact that it was driven from 'Fictitious Printing Plant' in Toronto, to 'Vista Cargo Centre - Pearson International Airport' in Mississauga, a distance of 26.9 km (16.7 miles). This establishes a workload of 0.019 metric tonne-kilometres, which when factored against the 1.6 MJ/tonne-km energy intensity factor for trucking published by Michael Landwehr and Céline Marie-Lilliu of the 'International Energy Agency' in 'Transportation Projections in OECD Regions, Detailed Report, May 2002'; Appendix 3, page 155, specific to North America, 2010 fleet (reported as 1.6 MJ/tonne-km of freight); gives us an energy requirement of 30 KJ.

NOTE #13: Because we modelled 'Diesel Oil of the IEA 2010 North American Default' quality as the fuel for this delivery, and because this fuel has a 'net calorific value' of 42,600 KJ/kg, we were able to calculate a fuel requirement of 0.001 kg (0.002 Lbs.). This quantity of fuel, factored against the emissions factors listed below, establishes the CO₂, CO, CH₄, NO+NO₂, N₂O, and NMVOC emissions stemming from this delivery.

NOTE #14: For the sake of comparison; when we multiply this same energy requirement for fuel of 30 KJ, by the fuel-type specific carbon dioxide emissions factor of 0.000074017 kg CO₂/KJ, based on the '2006 IPCC Guidelines for National Greenhouse Gas Inventories', Volume 2, Energy; Chapter 1, Introduction; Table 1.4; Pages 1.23 - 1.24; EXCEPT that the full-fledged scientific calculation was performed, such that 'Diesel Oil', with a default carbon content of 20.2 kg/GJ, when subject to 100% oxidation, and factored for the full molecular weights of CO₂/C (44.00945 / 12.01065), results in 74,017 kg CO₂/TJ (i.e. 20.2 * 1 * (44.00945 / 12.01065) = 74,017 kg CO₂/TJ). we thus arrive at 0.002 kg CO₂, when we specify the use of diesel oil. This figure is 99.395% of the CO₂ estimate established with reference to the IPCC emissions factor ID#19026. We take this as validation of our model, since this very slight discrepancy can be explained by our use of regional-standard fuels with differing NCVs, rounding errors, and the fact that we use molecular weights in our calculations that are defined out to five decimal places, compared to no decimal places as per the IPCC simplified method.

NOTE #15: With this assurance in our model's calculations, we can turn our attention to rectifying the 'carbon balance' of our calculations. This is necessary because both of the default carbon dioxide emissions factors noted above assume 100% oxidation of the fuel. This means that the other carbonaceous emissions calculated by our analysis, namely carbon monoxide (CO), methane (CH₄), and the non-methane volatile organic compounds (NMVOCs), will effectively count some carbon atoms twice. To avoid this error, we first calculated the CO₂ emissions that would result from the complete combustion of the identified CO and CH₄ emissions, and subtracted these sums from our carbon dioxide estimate. We then did the same thing for each one of the 14 organic



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gases identified in the US EPA's 'Speciate' (version 4.2) emissions profile (Profile ID# 2563), which together account for 0.006 grams of CO₂, and also subtracted this sum from our CO₂ estimate.

NOTE #16: ALTOGETHER, as noted above; our analysis reveals that the transport of the 0.71 kg (1.56 Lb.) hard cover book (corrugated packaging included); driven from 'Fictitious Printing Plant' in Toronto, to 'Vista Cargo Centre - Pearson International Airport' in Mississauga; on board a 'Heavy-Duty Truck' fuelled by diesel oil with a 'net calorific value' of 42,600 KJ/kg, RESULTED IN THE FOLLOWING AIRBORNE EMISSIONS: 0.0022 kg (0.0049 Lb.) of carbon dioxide (CO₂); 0.00001 kg (0.000022 Lb.) of carbon monoxide (CO); 0 kg (0 Lb.) of methane (CH₄); 0.000008 kg (0.000018 Lb.) of nitrogen oxides (NO_x); 0 kg (0 Lb.) of nitrous oxide (N₂O); and 0.000002 kg (0.000004 Lb.) of non-methane organic compounds (NMVOCs).

NOTE #17: Reference Notes RE: IPCC Emission Factor ID #19027 for diesel oil-fuelled heavy-duty truck freight, emitting carbon dioxide at the rate of 72.098 g/MJ; with applicability as USA / 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles). Data Provider: IPCC. Data provider email: ipcc-efdb@iges.or.jp *AND* RE: IPCC Emission Factor ID #19026 for diesel oil-fuelled heavy-duty truck freight, emitting carbon dioxide at the rate of 3172.31 g/kg fuel (equivalent to 3172.31 g/kg fuel); with application as US / 1996 IPCC Global Default. Data reported to EFDB: carbon dioxide emissions of 3172.31 g/kg fuel. Data source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles).

NOTE #18: Reference Notes RE: IPCC Emission Factor ID #19021 for diesel oil-fuelled heavy-duty truck freight, emitting carbon monoxide at the rate of 0.318 g/MJ; with applicability as USA / 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles). Data Provider: IPCC. Data provider email: ipcc-efdb@iges.or.jp *AND* RE: IPCC Emission Factor ID #19020 for diesel oil-fuelled heavy-duty truck freight, emitting carbon monoxide at the rate of 14.01 g/kg fuel (equivalent to 14.01 g/kg fuel); with application as US / 1996 IPCC Global Default. Data reported to EFDB: carbon monoxide emissions of 14.01 g/kg fuel. Data source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles).

NOTE #19: Reference Notes RE: IPCC Emission Factor ID #19015 for diesel oil-fuelled heavy-duty truck freight, emitting methane at the rate of 0.003 g/MJ; with applicability as USA / 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles). Data Provider: IPCC. Data provider email: ipcc-efdb@iges.or.jp *AND* RE: IPCC Emission Factor ID #19014 for diesel oil-fuelled heavy-duty truck freight, emitting methane at the rate of 0.14 g/kg fuel (equivalent to 0.14 g/kg fuel); with application as US / 1996 IPCC Global Default. Data reported to EFDB: methane emissions of 0.14 g/kg fuel. Data source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles).

NOTE #20: Reference Notes RE: IPCC Emission Factor ID #19012 for diesel oil-fuelled heavy-duty truck freight, emitting nitrogen oxides (NO+NO₂) at the rate of 0.257 g/MJ; with applicability as USA / 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles). Data Provider: IPCC. Data provider email: ipcc-efdb@iges.or.jp *AND* RE: IPCC Emission Factor ID #19011 for diesel oil-fuelled heavy-duty truck freight, emitting nitrogen oxides (NO+NO₂) at the rate of 11.32 g/kg fuel (equivalent to 11.32 g/kg fuel); with application as US / 1996 IPCC Global Default. Data reported to EFDB: nitrogen oxides (NO+NO₂) emissions of 11.32 g/kg fuel. Data source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles).

NOTE #21: Reference Notes RE: IPCC Emission Factor ID #19024 for diesel oil-fuelled heavy-duty truck freight, emitting nitrous oxide at the rate of 0.002 g/MJ; with applicability as USA / 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles). Data Provider: IPCC. Data provider email: ipcc-efdb@iges.or.jp *AND* RE: IPCC Emission Factor ID #19023 for diesel oil-fuelled heavy-duty truck freight, emitting nitrous oxide at the rate of 0.08 g/kg fuel (equivalent to 0.08 g/kg fuel); with application as US / 1996 IPCC Global Default. Data reported to EFDB: NITROUS OXIDE emissions of 0.08 g/kg fuel. Data source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles).

NOTE #22: Reference Notes RE: IPCC Emission Factor ID #19018 for diesel oil-fuelled heavy-duty truck freight, emitting non methane volatile organic compounds at the rate of 0.063 g/MJ; with applicability as USA / 1996 IPCC global default. Revised 1996



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IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles). Data Provider: IPCC. Data provider email: ipcc-efdb@iges.or.jp *AND* RE: IPCC Emission Factor ID #19017 for diesel oil-fuelled heavy-duty truck freight, emitting non methane volatile organic compounds at the rate of 2.78 g/kg fuel (equivalent to 2.78 g/kg fuel); with application as US / 1996 IPCC Global Default. Data reported to EFDB: NON methane VOLATILE ORGANIC COMPOUNDS emissions of 2.78 g/kg fuel. Data source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles).

NOTE #23: Delivery Leg 2 of 5 from: Lester B. Pearson International Airport, IATA Airport Code YYZ, Toronto, Canada; to: Detroit Metropolitan Wayne County Airport, IATA Airport Code DTW, Detroit, USA. This involves the further transport of the same package, a distance of 375.4 km (202.7 miles), establishing a 'workload' for this leg of 0.265 metric-tonne kilometres. After factoring for the energy requirements of the 'Bombardier CRJ-100ER' we modelled for, the need for 1,987 kilojoules of energy is established, which is the fuel equivalent of 0.045 kg of jet kerosene (assuming an NCV of 44,600 KJ/kg). By applying the '2006 IPCC Guidelines for National Greenhouse Gas Inventories'; but using an even more precise method than the one suggested there; we calculated our 'base carbon dioxide emissions' using a CO₂ intensity factor of 71 mg CO₂ per kilojoule of fuel combusted (at 100% oxidation). We also drew on a select panel of emissions factors to model other emissions, including; carbon monoxide (CO), methane (CH₄), nitrogen oxides (NO+NO₂), nitrous oxide (N₂O), and non-methane volatile organic compounds (NMVOCs). Because the CO, CH₄ and NMVOCs all contain carbon, we then reduced our 'base CO₂ estimate' to bring all of our emissions estimates into 'stoichiometric balance'.

NOTE #24: This airborne leg for the delivery of the 0.71 kg (1.56 Lb.) hard cover book (corrugated packaging included); with delivery from 'Lester B. Pearson International Airport' in Toronto, to 'Detroit Metropolitan Wayne County Airport' in Detroit; a flight of 375 km (203 nautical miles) based on the straight-line 'great circle' distance, plus a 9% 'uplift factor' as per IPCC guidelines (available online at <http://www.ipcc.ch/ipccreports/sres/aviation/121.htm#8223>); on board a 'Bombardier CRJ-100ER' fuelled by jet kerosene (of the IEA 2010 North American default specification); would require an estimated 0.04 kg of jet kerosene during cruise-level flight, and an estimated 0.01 kg during the take-off and landing (0.1 Lbs. and 0.02 Lbs., respectively).

NOTE #25: The combustion of this quantity of this fuel in this aircraft operating under these conditions, will result in the following airborne emissions; 0.17 kg (0.38 Lbs.) of carbon dioxide; 0.00045 kg (0.00098 Lbs.) of carbon monoxide; 0 kg (0 Lbs.) of methane; 0.00043 kg (0.00095 Lbs.) of nitrogen oxides (NO+NO₂); 0.000005 kg (0.000012 Lbs.) of nitrous oxide (N₂O); 0.000047 kg (0.000103 Lbs.) of non-methane volatile organic compounds (NMVOCs); and 0.000054 kg (0.00012 Lbs.) of sulphur oxides (SO₂+SO₃) emissions.

NOTE #26: With reliance on research performed by the 'Environmental Protection Agency' and the 'Federal Aviation Administration' in the United States; we can estimate the organic gas constituents that make up the NMVOC emissions, including: 7.97 mg of ethylene; 7.53 mg of C-10 paraffins; 6.34 mg of formaldehyde; 3.01 mg of C-10 olefins (modeled as trans-3,trans-6-decadiene); 3.01 mg of decanal; 2.34 mg of propylene; 2.20 mg of acetaldehyde; 2.03 mg of acetylene; 1.50 mg of 2-dodecenal; 1.26 mg of acrolein; 0.936 mg of glyoxal; 0.930 mg of methanol; 0.904 mg of isobutene/1-butene; 0.869 mg of 1,3-butadiene; 0.866 mg of benzene; 0.774 mg of methylglyoxal; 0.532 mg of crotonaldehyde; 0.400 mg of 1-pentene; 0.379 mg of 1-hexene; 0.375 mg of propionaldehyde; 0.374 mg of phenol; 0.338 mg of c4-benzene + c3-aroald; 0.331 mg of toluene; 0.279 mg of naphthalene; 0.276 mg of n-tridecane; 0.268 mg of ethane; 0.242 mg of benzaldehyde; 0.238 mg of n-dodecane; 0.229 mg of n-undecane; 0.226 mg of 1-heptene; 0.221 mg of methacrolein; 0.214 mg of n-tetradecane; 0.210 mg of 2-methylpentane; 0.190 mg of acetone; 0.185 mg of trans-2-pentene; 0.180 mg of 1,2,4-trimethylbenzene; 0.167 mg of c5-benzene + c4-aroald; 0.165 mg of n-decane; 0.159 mg of styrene; 0.143 mg of m-tolualdehyde; 0.142 mg of cis-2-pentene; 0.142 mg of 1-octene; 0.127 mg of 1-methyl naphthalene; 0.127 mg of 1-nonene; 0.126 mg of valeraldehyde; 0.118 mg of o-tolualdehyde; 0.108 mg of cis-2-butene; 0.106 mg of 2-methyl-naphthalene; 0.102 mg of n-pentane; 0.096 mg of c14-alkane (modeled as N-tetradecane); 0.095 mg of 1-decene; 0.095 mg of 2-methyl-2-butene; 0.091 mg of c15-alkane (modeled as N-pentadecane); 0.090 mg of ethylbenzene; 0.089 mg of n-pentadecane; 0.086 mg of o-xylene; 0.079 mg of m-ethyltoluene; 0.075 mg of c16-alkane (modeled as N-hexadecane); 0.073 mg of m-xylene; 0.073 mg of p-xylene; 0.072 mg of 2-methyl-1-butene; 0.061 mg of butyraldehyde; 0.058 mg of 3-methyl-1-butene; 0.055 mg of 1,2,3-trimethylbenzene; 0.046 mg of 2,6-dimethylnaphthalene; 0.040 mg of propane; 0.036 mg of 4-methyl-1-pentene; 0.033 mg of o-ethyltoluene; 0.033 mg of p-ethyltoluene; 0.033 mg of n-heptane; 0.032 mg of n-nonane; 0.032 mg of n-octane; 0.028 mg of 1,3,5-trimethylbenzene; 0.027 mg of n-propylbenzene; 0.025 mg of n-hexadecane; 0.025 mg of p-tolualdehyde; 0.018 mg of 2-methyl-1-pentene; 0.016 mg of isovaleraldehyde; 0.015 mg of trans-2-hexene; 0.005 mg of n-heptadecane; 0.002 mg of isopropylbenzene; and 0.001 mg of c18-alkane (modeled as N-octadecane).

NOTE #27: By applying the US EPA and FAA's "Recommended Best Practice for Quantifying Speciated Organic Gas Emissions from Aircraft Equipped with Turbofan, Turbojet, and Turboprop Engines, Version 1.0"; we were able to perform a 'carbon mass



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balance' calculation to ensure that no 'double counting' entered our estimates. At their foundations, our estimates are based on the following data points FOR CRUISE-LEVEL FLIGHT; for carbon dioxide we drew upon IPCC Emission Factor ID #110550 which establishes a rate of emissions of 3150 kg/tonne fuel (Jet Kerosene) burned in a Jet Aircraft (Generic); for carbon monoxide we drew upon IPCC Emission Factor ID #110541 which establishes a rate of emissions of 7 kg/tonne fuel (Jet Kerosene) burned in a Jet Aircraft (Generic); for methane we drew upon IPCC Emission Factor ID #110553 which establishes a rate of emissions of 0 kg/tonne fuel (Jet Kerosene) burned in a Jet Aircraft (Generic); for nitrogen oxides (NO+NO₂) we drew upon the 2006 IPCC Volume 2, Chapter 3, Table 3.6.10 Bombardier CRJ-100ER jet aircraft emission factor for NO_x which establishes a rate of emissions of 8 g/kg (Jet Kerosene) burned in a Jet Aircraft - CRJ-100ER; for nitrous oxide we drew upon IPCC Emission Factor ID #110535 which establishes a rate of emissions of 0.1 kg/tonne fuel (Jet Kerosene) burned in a Jet Aircraft (Generic); for non methane volatile organic compounds we drew upon IPCC Emission Factor ID #110544 which establishes a rate of emissions of 0.7 kg/tonne fuel (Jet Kerosene) burned in a Jet Aircraft (Generic); and for sulphur dioxides (SO₂+SO₃) we drew upon IPCC Emission Factor ID #110547 which establishes a rate of emissions of 1 kg/tonne fuel (Jet Kerosene) burned in a Jet Aircraft (Generic).

NOTE #28: To calculate fuel requirements, a number of factors were considered. First was the weight of the 0.71 kg (1.56 Lb.) hard cover book (including corrugated packaging), and the fact that it was flown from 'Lester B. Pearson International Airport' in Toronto, to 'Detroit Metropolitan Wayne County Airport' in Detroit; a flight of 375 km (203 nautical miles). This establishes a workload of 0.26 metric tonne-kilometres, which when factored against the 7.5 MJ/tonne-km energy intensity factor, as published by Michael Landwehr and Céline Marie-Lilliu of the 'International Energy Agency' in 'Transportation Projections in OECD Regions, Detailed Report, May 2002'; Appendix 3, page 155, specific to North America, 2010 fleet (reported as 7.5 MJ/tonne-km of freight); establishes an energy requirement of 1,987 KJ.

NOTE #29: Because we modelled 'Jet Kerosene of the IEA 2010 North American Default' quality as the fuel for this flight, and because this fuel has a 'net calorific value' of 44,600 KJ/kg, we were able to calculate a fuel requirement for cruise-level flight of 0.045 kg (0.098 Lbs.). This quantity of fuel, factored against the emissions factors listed below, establishes the CO₂, CO, CH₄, NO+NO₂, N₂O, NMVOC and SO₂+SO₃ emissions stemming from cruise-level flight.

NOTE #30: We then used the 'European Environment Agency' (EEA), 'European Monitoring and Evaluation Programme' (EMEP) data set known as 'CORINAIR' to model emissions during the landing and take-off (LTO) cycle. This involved selecting a representative aircraft from the CORINAIR data set that was comparable to the 'Bombardier CRJ-100ER' modelled for this flight; in this case the 'Embraer 110P2A'. Unlike the aforementioned factors used to calculate cruise-level emissions, which establish emissions rates on a fuel usage basis; the CORINAIR data pertains to whole-aircraft fuel requirements and emissions. The CORINAIR data distinguishes between flight operations above an altitude of 914 M, termed 'climb-cruise-descent' (CCD), and operations below 914 M, termed 'landing and take-off' (LTO). This permitted the calculation of ratios, specific to a flight of between 231.5 km and 463 km, which enabled us to simulate fuel requirements and emissions during the LTO cycle, by factoring against our cruise-level estimates.

NOTE #31: To do this, we applied the fuel consumption ratio we observed in the CORINAIR data set for a 'Embraer 110P2A' flying between 231.5 km and 463 km, to model an LTO fuel requirement equal to 0.218 that of the CCD fuel requirement. This same ratio was also applied to *preliminary* CO₂ emissions estimates and also to sulphur oxides emissions estimates, as these aspects of emissions are highly dependent on fuel consumption. We used the CORINAIR ratio of 0.211 for nitrogen oxides emissions (LTO/CCD), to estimate NO_x and N₂O emissions during LTO, in similar fashion. The CORINAIR ratio of 0.502 for hydrocarbons emissions (also LTO/CCD, of course), was factored against cruise level emissions estimates for NMVOCs and also for methane (CH₄) emissions, although, the base estimate for CH₄ emissions was zero. The CORINAIR ratio of 0.427 for carbon monoxide was applied to the CCD CO emissions estimate in order to derive CO emissions during LTO. Altogether, these estimates for CCD and LTO emissions were aggregated to establish 'whole flight' emissions.

NOTE #32: At this point in our calculations, we focused our attention directly on the carbon dioxide estimates, which constitute the overwhelming bulk of the greenhouse gas emissions from aviation. Our model approaches this calculation from two different angles. In the first case, we multiplied the 0.26 MT-km workload by the 7.5 MJ/MT-km energy intensity factor published by Michael Landwehr and Céline Marie-Lilliu of the 'International Energy Agency' in 'Transportation Projections in OECD Regions, Detailed Report, May 2002'; Appendix 3, page 155, specific to North America, 2010 fleet (reported as 7.5 MJ/tonne-km of freight); for air cargo. Further multiplying the product of this calculation by 1000 establishes the kilojoules requirement for fuel (i.e. 1,987 KJ). When we divide this KJ requirement for fuel by the 'net calorific value' of the IPCC 2006 'default' grade of jet kerosene (which is 44,100 KJ/kg), we arrive at a fuel requirement of 0.05 kg. When this amount of fuel is factored against the aforementioned IPCC Emission Factor ID #110550 which establishes a rate of emissions of 3150 kg/tonne fuel (or 3150 g/kg fuel), we find that 0.05 kg fuel * 3150 g CO₂/kg fuel = 0.14 kg CO₂ from cruise-level flight.



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NOTE #33: For the sake of comparison; when we multiply this same energy requirement for fuel of 1,987 KJ, by the fuel-type specific carbon dioxide emissions factor of 0.000071452 kg CO₂/KJ, based on the '2006 IPCC Guidelines for National Greenhouse Gas Inventories' (Volume 2, Energy; Chapter 1, Introduction; Table 1.4; Pages 1.23 - 1.24); EXCEPT that we perform the full-fledged scientific calculation, such that 'Jet Kerosene', with a default carbon content of 19.5 kg/GJ, when subject to 100% oxidation, and factored for the full molecular weights of CO₂/C (44.00945 / 12.01065), results in 71,452 kg CO₂/TJ; we thus arrive at 0.14 kg CO₂ from cruise-level flight, when we specify the use of jet kerosene of the 'IEA 2010 North American Default' standard. This figure is 101.167% of the CO₂ estimate established with reference to the IPCC emissions factor ID#110550. We take this as validation of our model, since this very slight discrepancy can be explained by our use of regional-standard fuels with differing NCVs, rounding errors, and the fact that we use molecular weights in our calculations that are defined out to five decimal places, compared to no decimal places as per the IPCC simplified method.

NOTE #34: Again, for the sake of comparison; when we draw upon a different series of emissions factors from the IPCC's 'Emission Factor Database' (EFDB); a series that is expressed in terms of grams of emissions per megajoule (g/MJ), and we perform essentially the same kind of calculations, we are pleased by the results. As we expected, there are significant differences between the results derived from this comparison, but this is explainable by the fact that the g/MJ emission factors are calculated with reference to a 'generic' jet aircraft, without reference to differing NCVs of aviation fuels, and without a stoichiometric balancing of carbon contents in the various gases. In this comparison; using EF ID #12126, we compute CO₂ emissions that are 100.686% of our model's result; using EF ID #18244, we compute CO emissions that are 63.714% of our model's result; using EF ID #119017, we compute NO_x emissions that are 139.375% of our model's result; using EF ID #119014, we compute N₂O emissions that are 89.2% of our model's result; using EF ID #18284, we compute NMVOC emissions that are 318.571% of our model's result; using EF ID #190, we compute SO_x emissions that are 101.242% of our model's result; which seems reasonable, all things considered. This too, we take as validation of our model, since the emissions most dependent on fuel consumption are also the ones that come closest to 100% of our preferred estimates.

NOTE #35: Once more, for the sake of comparison; when we apply the guidelines of the United States 'Environmental Protection Agency' (EPA), published in "CLIMATE LEADERS — Greenhouse Gas Inventory Protocol Core Module Guidance: Direct Emissions from Mobile Combustion Sources"; we find that the 'fuel consumption method' for calculating emissions is favoured as the most accurate way to estimate emissions from freight transport. To this end, we have drawn upon the N₂O and CH₄ emission factors for jet fuel of 0.1 g/kg fuel used, and 0.087 g/kg fuel used, respectively, that are found in 'Table A-6: CH₄ and N₂O Emission Factors for Non-Highway Vehicles', on page 24. For a CO₂ emission factor we turned to 'Table B-2: Factors for Calculating CO₂ Emissions from Fuel Oil, Aviation Gasoline, and Jet Fuel Use', on page 27. This table notes an emission factor of 9.57 kg-CO₂ per US Gallon of fuel used, which when factored by the fuel density value from Table A-6 of 3.08 kg/US Gallon, establishes a carbon dioxide emission factor of 3.107 kg-CO₂ per kg of fuel (or 3,107 g-CO₂/kg fuel). When we apply these US EPA emission factors to the jet kerosene fuel requirement we have established for this delivery, we arrived at the following results: Given the requirement for 0.045 kg of jet kerosene (0.014 US gallons) for *cruise-level* flight, the US EPA estimate for carbon dioxide would be 0.14 kg-CO₂; for nitrous oxide would be 0.000004 kg-N₂O, and for methane would be 0.000004 kg-CH₄. Because the IPCC and EEA data sets we have relied on do not include methane emissions from aviation (as aviation is deemed an insignificant or non-existent source), we cannot compare the US EPA's estimate for methane to any of our figures. As for carbon dioxide, the EPA's estimate is 98.64% of our model's estimate (which we still prefer, as our CO₂ estimate is stoichiometrically balanced); while the nitrous oxide estimate based on the EPA's factors is 100.00% of our model's estimate. On the whole, we take these calculations as further validation of our model and our methods.

NOTE #36: With this assurance in our model's calculations, we can turn our attention to rectifying the 'carbon balance' of our calculations. This is necessary because both of the default carbon dioxide emissions factors noted above assume 100% oxidation of the fuel. This means that the other carbonaceous emissions calculated by our analysis, namely carbon monoxide (CO), methane (CH₄), and the non-methane volatile organic compounds (NMVOCs), will effectively count some carbon atoms twice. To avoid this error, we first calculated the CO₂ emissions that would result from the complete combustion of the identified CO and CH₄ emissions, and subtracted these sums from our carbon dioxide estimate. We then did the same thing for each one of the 82 organic gases identified in the US EPA/FAA's aviation emissions profile, which together account for 0.147 grams of CO₂, and also subtracted this sum from our CO₂ estimate.

NOTE #37: ALTOGETHER, as noted above; our analysis reveals that the transport of the 0.71 kg (1.56 Lb.) hard cover book (corrugated packaging included); flown from 'Lester B. Pearson International Airport' in Toronto, to 'Detroit Metropolitan Wayne County Airport' in Detroit; on board a 'Bombardier CRJ-100ER' fuelled by jet kerosene (of the IEA 2010 North American default specification), RESULTED IN THE FOLLOWING AIRBORNE EMISSIONS: 0.17 kg (0.38 Lb.) of carbon dioxide (CO₂); 0.00045 kg (0.00098 Lb.) of carbon monoxide (CO); 0 kg (0 Lb.) of methane (CH₄); 0.00043 kg (0.00095 Lb.) of nitrogen oxides (NO_x);



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0.000005 kg (0.000012 Lb.) of nitrous oxide (N₂O); 0.000047 kg (0.000103 Lb.) of non-methane organic compounds (NMVOCs); and 0.000054 kg (0.00012 Lb.) of sulphur oxides (SO_x).

NOTE #38: Reference Notes RE: Emission factor found in the 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories' (Table 1-52 on Page 1.98) of the Reference Manual 'Default Emission factors and Fuel Consumption for Aircraft' (NB: LTO emission factors are given on a per-aircraft basis.) Worksheet 1-5; Sheet 3-3. This applies to international flights. Emission Factor Reported to EFDB: 3150 kg/t fuel (equivalent to 3150 g/kg fuel). Data Provider: IPCC. Data Provider Contact: ipcc-efdb@iges.or.jp

NOTE #39: Reference Notes RE: Emission factor found in the 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories' (Table 1-52 on Page 1.98) of the Reference Manual 'Default Emission factors and Fuel Consumption for Aircraft' (NB: LTO emission factors are given on a per-aircraft basis.) Worksheet 1-5; Sheet 3-3. This applies to domestic flights. Emission Factor Reported to EFDB: 7 kg/t fuel (equivalent to 7 g/kg fuel). Data Provider: IPCC. Data Provider Contact: ipcc-efdb@iges.or.jp

NOTE #40: Reference Notes RE: Emission factor found in the 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories' (Table 1-52 on Page 1.98) of the Reference Manual 'Default Emission factors and Fuel Consumption for Aircraft' (NB: LTO emission factors are given on a per-aircraft basis.) Worksheet 1-5; Sheet 3-3. This applies to international flights. Studies indicate that during cruise no methane is emitted. Emission Factor Reported to EFDB: 0 kg/t fuel (equivalent to 0 g/kg fuel). Data Provider: IPCC. Data Provider Contact: ipcc-efdb@iges.or.jp

NOTE #41: Reference Notes RE: Emission factor found in IPCC Guidelines indicating 8 g NO_x emissions per kg fuel used in the regional jet 'CRJ-100ER'. Data Source: '2006 IPCC Guidelines for National Greenhouse Gas Inventories', Volume 2, Energy; Chapter 3, Mobile Combustion; Table 3.6.10; Nox Emission Factors for Various Aircraft at Cruise Levels; Page 3.72, IN REFERENCE TO: Sutkus, D.J., Baughcum, S.L., DuBois, D.P.,(2001) 'Scheduled civil aircraft emission inventories for 1999: database development and Analysis.' NASA/CR—2001-211216, National Aeronautics and Space Administration, Glenn Research Center, USA, October 2001.

NOTE #42: Reference Notes RE: Emission factor found in the 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories' (Table 1-52 on Page 1.98) of the Reference Manual 'Default Emission factors and Fuel Consumption for Aircraft' (NB: LTO emission factors are given on a per-aircraft basis.) Worksheet 1-5; Sheet 3-3. This applies to domestic flights. Estimates are based on Tier 1 default values. Emission Factor Reported to EFDB: 0.1 kg/t fuel (equivalent to 0.1 g/kg fuel). Data Provider: IPCC. Data Provider Contact: ipcc-efdb@iges.or.jp

NOTE #43: Reference Notes RE: Emission factor found in the 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories' (Table 1-52 on Page 1.98) of the Reference Manual 'Default Emission factors and Fuel Consumption for Aircraft' (NB: LTO emission factors are given on a per-aircraft basis.) Worksheet 1-5; Sheet 3-3. This applies to domestic flights. Studies indicate that no methane is emitted during cruise. Emission Factor Reported to EFDB: 0.7 kg/t fuel (equivalent to 0.7 g/kg fuel). Data Provider: IPCC. Data Provider Contact: ipcc-efdb@iges.or.jp

NOTE #44: Reference Notes RE: Emission factor found in the 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories' (Table 1-52 on Page 1.98) of the Reference Manual 'Default Emission factors and Fuel Consumption for Aircraft' (NB: LTO emission factors are given on a per-aircraft basis.) Worksheet 1-5; Sheet 3-3. This applies to domestic flights. Sulphur content of the fuel is assumed to be 0.05% for both LTO and cruise activities. Emission Factor Reported to EFDB: 1 kg/t fuel (equivalent to 1 g/kg fuel). Data Provider: IPCC. Data Provider Contact: ipcc-efdb@iges.or.jp

NOTE #45: Reference Notes RE: IPCC Emission Factor ID #12126 for jet kerosene-fuelled generic civilian jet aircraft-borne freight, emitting carbon dioxide at the rate of 71590.0000 g/GJ (equivalent to 71.59 g/MJ); with applicability as Europe / EEA / CITEPA default. Source data from CORINAIR 94. Data Provider: EEA/CITEPA.

NOTE #46: Reference Notes RE: IPCC Emission Factor ID #18244 for jet kerosene-fuelled generic civilian jet aircraft-borne freight, emitting carbon monoxide at the rate of 100 KG/TJ (equivalent to 0.1 g/MJ); with applicability as 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-10 on Page 1.40 of the Reference Manual). IPCC Worksheet 1-3; Sheet 2 - 3. Data Provider: IPCC. Data Provider Comments: The following default emission factors have been developed by the IPCC based on CORINAIR90 among others. These factors are considered the best available global default factors to date. Data provider email: ipcc-efdb@iges.or.jp

NOTE #47: Reference Notes RE: IPCC Emission Factor ID #18124 for jet kerosene-fuelled generic civilian jet aircraft-borne freight, emitting methane at the rate of 0.5 KG/TJ (equivalent to 0.0005 g/MJ); with applicability as 1996 IPCC global default. Revised 1996

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IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-7 on Page 1.35 of the Reference Manual). IPCC Worksheet 1-3; Sheet 2 - 3. Data Provider: IPCC. Data Provider Comments: These factors are considered the best available global default factors to date. Data provider email: ipcc-efdb@iges.or.jp

NOTE #48: Reference Notes RE: IPCC Emission Factor ID #119017 for jet kerosene-fuelled generic jet aircraft-borne freight, emitting nitrogen oxides (NO+NO₂) at the rate of 250 kg/TJ (equivalent to 0.25 g/MJ); with application as 2006 IPCC Global Default. Data reported to EFDB: nitrogen oxides (NO+NO₂) emissions of 250 kg/TJ (kg/TJ). Data source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy, Table 3.6.5; Equation 3.6.1. Technical Reference: Expert judgement by the authors of Section 3.6, Volume 2 of the 2006 IPCC Guidelines. Confidence limits: Upper: +25%, Lower: -25%. NB: Tier 1 assumes that all aircraft have the same emission factors based on the rate of fuel consumption.

NOTE #49: Reference Notes RE: IPCC Emission Factor ID #119014 for jet kerosene-fuelled generic jet aircraft-borne freight, emitting nitrous oxide at the rate of 2 kg/TJ (equivalent to 0.002 g/MJ); with application as 2006 IPCC Global Default. Data reported to EFDB: NITROUS OXIDE emissions of 2 kg/TJ (kg/TJ). Data source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy, Table 3.6.5; Equation 3.6.1. IPCC Worksheet: 1A, Sheet 1 of 4 (page A1.6) in Annex 1 of Volume 2. Technical Reference: IPCC (1999). "Aviation and the global atmosphere." Eds: Penner, J.E., Lister, D.H., Griggs, D.J., Dokken, D.J., McFarland, M., Intergovernmental Panel on Climate Change, Cambridge University Press 1999. Confidence limits: Upper: +150%, Lower: -70%. NB: Tier 1 assumes that all aircraft have the same emission factors based on the rate of fuel consumption.

NOTE #50: Reference Notes RE: IPCC Emission Factor ID #18284 for jet kerosene-fuelled generic civilian jet aircraft-borne freight, emitting non methane volatile organic compounds at the rate of 50 KG/TJ (equivalent to 0.05 g/MJ); with applicability as 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-11 on Page 1.42 of the Reference Manual). IPCC Worksheet 1-3; Sheet 2 - 3. Data Provider: IPCC. Data Provider Comments: The following default emission factors have been developed by the IPCC based on CORINAIR90 among others. This emission factor is for jet kerosene. The emission factor for aviation gasoline is 300kg/TJ. Data provider email: ipcc-efdb@iges.or.jp

NOTE #51: Reference Notes RE: IPCC Emission Factor ID #190 for jet kerosene-fuelled generic jet aircraft-borne freight, emitting sulphur dioxides (SO₂+SO₃) at the rate of 22.7000 g/GJ (equivalent to 0.0227 g/MJ); with application as European EEA/CITEPA Default. Data reported to EFDB: SULPHUR DIOXIDE (SO₂+SO₃) emissions of 22.7000 g/GJ. Data source: CORINAIR 94.

NOTE #52: Reference Notes RE: the CORINAIR data used to estimate emissions due to the landing-and-takeoff (LTO) cycle; with a fuel requirement and emissions profile specific to a 'Embraer 110P2A', used to model LTO-cycle emissions for a flight of between 231.5 km and 463 km. (This aircraft was deemed to be a representative proxy for a 'Bombardier CRJ-100ER'.) To do this, we calculated the ratios for the fuel requirement, and NO_x, HC and CO emissions for the 'climb-cruise-descent' (CCD) phase of flight, 'over' the 'landing-and-takeoff' (LTO) cycle; then used this ratio to estimate LTO-cycle emissions, factoring against our estimates for cruise-level emissions, which are based on IPCC and EEA emissions factors. For fuel, this aircraft flying this distance used 224.7 kg during CCD and 48.9 kg during LTO; for a ratio of LTO/CCD = 0.21762. For NO_x, this aircraft emitted 1.309 kg during CCD and 0.276 kg during LTO; for a ratio of LTO/CCD = 0.21085. For hydrocarbons, this aircraft emitted 48.6 kg during CCD and 24.4 kg during LTO; for a ratio of LTO/CCD = 0.50206. For carbon monoxide, this aircraft emitted 869.2 kg during CCD and 371.4 kg during LTO; for a ratio of LTO/CCD = 0.42729. We applied the fuel use ratio to our CO₂ and SO_x estimates, the NO_x ratio was applied to our NO_x and N₂O estimates, the HC ratio was applied to our CH₄ and NMVOC estimates, and the CO ratio was applied to our CO estimates. These derived LTO estimates were aggregated with our CCD estimates, then stoichiometrically balanced in our model, as explained above. The CORINAIR data set is available online from www.eea.europa.eu.

NOTE #53: Reference Notes RE: the emissions factors drawn from the United States 'Environmental Protection Agency', Office of Air and Radiation: 'CLIMATE LEADERS – Greenhouse Gas Inventory Protocol Core Module Guidance, Direct Emissions from Mobile Combustion Sources' (EPA430-K-08-004), available online at www.epa.gov/climateleaders.

NOTE #54: Delivery Leg 3 of 5 from: Detroit Metropolitan Wayne County Airport, IATA Airport Code DTW, Detroit, USA; to: Chicago Midway International Airport, IATA Airport Code MDW, Chicago, USA. This involves the further transport of the same package, a distance of 400.0 km (216.0 miles), establishing a 'workload' for this leg of 0.282 metric-tonne kilometres. After factoring for the energy requirements of the 'Embraer ERJ145' we modelled for, the need for 2,117 kilojoules of energy is established, which is the fuel equivalent of 0.047 kg of jet kerosene (assuming an NCV of 44,600 KJ/kg). By applying the '2006 IPCC Guidelines for National Greenhouse Gas Inventories'; but using an even more precise method than the one suggested there; we calculated our 'base carbon dioxide emissions' using a CO₂ intensity factor of 71 mg CO₂ per kilojoule of fuel combusted (at 100% oxidation). We also drew on a select panel of emissions factors to model other emissions, including; carbon monoxide (CO), methane (CH₄), nitrogen oxides (NO+NO₂), nitrous oxide (N₂O), and non-methane volatile organic compounds (NMVOCs). Because the CO, CH₄ and



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NMVOCs all contain carbon, we then reduced our 'base CO2 estimate' to bring all of our emissions estimates into 'stoichiometric balance'.

NOTE #55: This airborne leg for the delivery of the 0.71 kg (1.56 Lb.) hard cover book (corrugated packaging included); with delivery from 'Detroit Metropolitan Wayne County Airport' in Detroit, to 'Chicago Midway International Airport' in Chicago; a flight of 400 km (216 nautical miles) based on the straight-line 'great circle' distance, plus a 9% 'uplift factor' as per IPCC guidelines (available online at <http://www.ipcc.ch/ipccreports/sres/aviation/121.htm#8223>); on board a 'Embraer RJ145EP (EMB-145EP)' fuelled by jet kerosene (of the IEA 2010 North American default specification); would require an estimated 0.05 kg of jet kerosene during cruise-level flight, and an estimated 0.01 kg during the take-off and landing (0.1 Lbs. and 0.02 Lbs., respectively).

NOTE #56: The combustion of this quantity of this fuel in this aircraft operating under these conditions, will result in the following airborne emissions; 0.18 kg (0.4 Lbs.) of carbon dioxide; 0.00047 kg (0.00105 Lbs.) of carbon monoxide; 0 kg (0 Lbs.) of methane; 0.00045 kg (0.001 Lbs.) of nitrogen oxides (NO+NO₂); 0.000006 kg (0.000013 Lbs.) of nitrous oxide (N₂O); 0.00005 kg (0.00011 Lbs.) of non-methane volatile organic compounds (NMVOCs); and 0.000058 kg (0.000127 Lbs.) of sulphur oxides (SO₂+SO₃) emissions.

NOTE #57: With reliance on research performed by the 'Environmental Protection Agency' and the 'Federal Aviation Administration' in the United States; we can estimate the organic gas constituents that make up the NMVOC emissions, including: 8.49 mg of ethylene; 8.02 mg of C-10 paraffins; 6.76 mg of formaldehyde; 3.21 mg of C-10 olefins (modeled as trans-3,trans-6-decadiene); 3.21 mg of decanal; 2.49 mg of propylene; 2.35 mg of acetaldehyde; 2.16 mg of acetylene; 1.60 mg of 2-dodecenal; 1.34 mg of acrolein; 0.997 mg of glyoxal; 0.991 mg of methanol; 0.963 mg of isobutene/1-butene; 0.926 mg of 1,3-butadiene; 0.923 mg of benzene; 0.825 mg of methylglyoxal; 0.567 mg of crotonaldehyde; 0.426 mg of 1-pentene; 0.404 mg of 1-hexene; 0.399 mg of propionaldehyde; 0.399 mg of phenol; 0.360 mg of c4-benzene + c3-aroald; 0.352 mg of toluene; 0.297 mg of naphthalene; 0.294 mg of n-tridecane; 0.286 mg of ethane; 0.258 mg of benzaldehyde; 0.254 mg of n-dodecane; 0.244 mg of n-undecane; 0.240 mg of 1-heptene; 0.236 mg of methacrolein; 0.228 mg of n-tetradecane; 0.224 mg of 2-methylpentane; 0.203 mg of acetone; 0.197 mg of trans-2-pentene; 0.192 mg of 1,2,4-trimethylbenzene; 0.178 mg of c5-benzene + c4-aroald; 0.176 mg of n-decane; 0.170 mg of styrene; 0.153 mg of m-tolualdehyde; 0.152 mg of cis-2-pentene; 0.152 mg of 1-octene; 0.136 mg of 1-methyl naphthalene; 0.135 mg of 1-nonene; 0.134 mg of valeraldehyde; 0.126 mg of o-tolualdehyde; 0.115 mg of cis-2-butene; 0.113 mg of 2-methyl-naphthalene; 0.109 mg of n-pentane; 0.102 mg of c14-alkane (modeled as N-tetradecane); 0.102 mg of 1-decene; 0.102 mg of 2-methyl-2-butene; 0.097 mg of c15-alkane (modeled as N-pentadecane); 0.096 mg of ethylbenzene; 0.095 mg of n-pentadecane; 0.091 mg of o-xylene; 0.085 mg of m-ethyltoluene; 0.080 mg of c16-alkane (modeled as N-hexadecane); 0.077 mg of m-xylene; 0.077 mg of p-xylene; 0.077 mg of 2-methyl-1-butene; 0.065 mg of butyraldehyde; 0.061 mg of 3-methyl-1-butene; 0.058 mg of 1,2,3-trimethylbenzene; 0.049 mg of 2,6-dimethylnaphthalene; 0.043 mg of propane; 0.038 mg of 4-methyl-1-pentene; 0.036 mg of o-ethyltoluene; 0.035 mg of p-ethyltoluene; 0.035 mg of n-heptane; 0.034 mg of n-nonane; 0.034 mg of n-octane; 0.030 mg of 1,3,5-trimethylbenzene; 0.029 mg of n-propylbenzene; 0.027 mg of n-hexadecane; 0.026 mg of p-tolualdehyde; 0.019 mg of 2-methyl-1-pentene; 0.018 mg of isovaleraldehyde; 0.016 mg of trans-2-hexene; 0.005 mg of n-heptadecane; 0.002 mg of isopropylbenzene; and 0.001 mg of c18-alkane (modeled as N-octadecane).

NOTE #58: By applying the US EPA and FAA's "Recommended Best Practice for Quantifying Speciated Organic Gas Emissions from Aircraft Equipped with Turbofan, Turbojet, and Turboprop Engines, Version 1.0"; we were able to perform a 'carbon mass balance' calculation to ensure that no 'double counting' entered our estimates. At their foundations, our estimates are based on the following data points FOR CRUISE-LEVEL FLIGHT; for carbon dioxide we drew upon IPCC Emission Factor ID #110550 which establishes a rate of emissions of 3150 kg/tonne fuel (Jet Kerosene) burned in a Jet Aircraft (Generic); for carbon monoxide we drew upon IPCC Emission Factor ID #110541 which establishes a rate of emissions of 7 kg/tonne fuel (Jet Kerosene) burned in a Jet Aircraft (Generic); for methane we drew upon IPCC Emission Factor ID #110553 which establishes a rate of emissions of 0 kg/tonne fuel (Jet Kerosene) burned in a Jet Aircraft (Generic); for nitrogen oxides (NO+NO₂) we drew upon the 2006 IPCC Volume 2, Chapter 3, Table 3.6.10 Embraer ERJ-145 jet aircraft emission factor for NO_x which establishes a rate of emissions of 7.9 g/kg (Jet Kerosene) burned in a Jet Aircraft - ERJ-145; for nitrous oxide we drew upon IPCC Emission Factor ID #110535 which establishes a rate of emissions of 0.1 kg/tonne fuel (Jet Kerosene) burned in a Jet Aircraft (Generic); for non methane volatile organic compounds we drew upon IPCC Emission Factor ID #110544 which establishes a rate of emissions of 0.7 kg/tonne fuel (Jet Kerosene) burned in a Jet Aircraft (Generic); and for sulphur dioxides (SO₂+SO₃) we drew upon IPCC Emission Factor ID #110547 which establishes a rate of emissions of 1 kg/tonne fuel (Jet Kerosene) burned in a Jet Aircraft (Generic).

NOTE #59: To calculate fuel requirements, a number of factors were considered. First was the weight of the 0.71 kg (1.56 Lb.) hard cover book (including corrugated packaging), and the fact that it was flown from 'Detroit Metropolitan Wayne County Airport' in Detroit, to 'Chicago Midway International Airport' in Chicago; a flight of 400 km (216 nautical miles). This establishes a workload of 0.28 metric tonne-kilometres, which when factored against the 7.5 MJ/tonne-km energy intensity factor, as published by Michael



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Landwehr and Céline Marie-Lilliu of the 'International Energy Agency' in 'Transportation Projections in OECD Regions, Detailed Report, May 2002'; Appendix 3, page 155, specific to North America, 2010 fleet (reported as 7.5 MJ/tonne-km of freight); establishes an energy requirement of 2,117 KJ.

NOTE #60: Because we modelled 'Jet Kerosene of the IEA 2010 North American Default' quality as the fuel for this flight, and because this fuel has a 'net calorific value' of 44,600 KJ/kg, we were able to calculate a fuel requirement for cruise-level flight of 0.047 kg (0.105 Lbs.). This quantity of fuel, factored against the emissions factors listed below, establishes the CO₂, CO, CH₄, NO+NO₂, N₂O, NMVOC and SO₂+SO₃ emissions stemming from cruise-level flight.

NOTE #61: We then used the 'European Environment Agency' (EEA), 'European Monitoring and Evaluation Programme' (EMEP) data set known as 'CORINAIR' to model emissions during the landing and take-off (LTO) cycle. This involved selecting a representative aircraft from the CORINAIR data set that was comparable to the 'Embraer ERJ145' modelled for this flight; in this case the 'Embraer 110P2A'. Unlike the aforementioned factors used to calculate cruise-level emissions, which establish emissions rates on a fuel usage basis; the CORINAIR data pertains to whole-aircraft fuel requirements and emissions. The CORINAIR data distinguishes between flight operations above an altitude of 914 M, termed 'climb-cruise-descent' (CCD), and operations below 914 M, termed 'landing and take-off' (LTO). This permitted the calculation of ratios, specific to a flight of between 231.5 km and 463 km, which enabled us to simulate fuel requirements and emissions during the LTO cycle, by factoring against our cruise-level estimates.

NOTE #62: To do this, we applied the fuel consumption ratio we observed in the CORINAIR data set for a 'Embraer 110P2A' flying between 231.5 km and 463 km, to model an LTO fuel requirement equal to 0.218 that of the CCD fuel requirement. This same ratio was also applied to *preliminary* CO₂ emissions estimates and also to sulphur oxides emissions estimates, as these aspects of emissions are highly dependent on fuel consumption. We used the CORINAIR ratio of 0.211 for nitrogen oxides emissions (LTO/CCD), to estimate NO_x and N₂O emissions during LTO, in similar fashion. The CORINAIR ratio of 0.502 for hydrocarbons emissions (also LTO/CCD, of course), was factored against cruise level emissions estimates for NMVOCs and also for methane (CH₄) emissions, although, the base estimate for CH₄ emissions was zero. The CORINAIR ratio of 0.427 for carbon monoxide was applied to the CCD CO emissions estimate in order to derive CO emissions during LTO. Altogether, these estimates for CCD and LTO emissions were aggregated to establish 'whole flight' emissions.

NOTE #63: At this point in our calculations, we focused our attention directly on the carbon dioxide estimates, which constitute the overwhelming bulk of the greenhouse gas emissions from aviation. Our model approaches this calculation from two different angles. In the first case, we multiplied the 0.28 MT-km workload by the 7.5 MJ/MT-km energy intensity factor published by Michael Landwehr and Céline Marie-Lilliu of the 'International Energy Agency' in 'Transportation Projections in OECD Regions, Detailed Report, May 2002'; Appendix 3, page 155, specific to North America, 2010 fleet (reported as 7.5 MJ/tonne-km of freight); for air cargo. Further multiplying the product of this calculation by 1000 establishes the kilojoules requirement for fuel (i.e. 2,117 KJ). When we divide this KJ requirement for fuel by the 'net calorific value' of the IPCC 2006 'default' grade of jet kerosene (which is 44,100 KJ/kg), we arrive at a fuel requirement of 0.05 kg. When this amount of fuel is factored against the aforementioned IPCC Emission Factor ID #110550 which establishes a rate of emissions of 3150 kg/tonne fuel (or 3150 g/kg fuel), we find that 0.05 kg fuel * 3150 g CO₂/kg fuel = 0.15 kg CO₂ from cruise-level flight.

NOTE #64: For the sake of comparison; when we multiply this same energy requirement for fuel of 2,117 KJ, by the fuel-type specific carbon dioxide emissions factor of 0.000071452 kg CO₂/KJ, based on the '2006 IPCC Guidelines for National Greenhouse Gas Inventories' (Volume 2, Energy; Chapter 1, Introduction; Table 1.4; Pages 1.23 - 1.24); EXCEPT that we perform the full-fledged scientific calculation, such that 'Jet Kerosene', with a default carbon content of 19.5 kg/GJ, when subject to 100% oxidation, and factored for the full molecular weights of CO₂/C (44.00945 / 12.01065), results in 71,452 kg CO₂/TJ; we thus arrive at 0.15 kg CO₂ from cruise-level flight, when we specify the use of jet kerosene of the 'IEA 2010 North American Default' standard. This figure is 101.167% of the CO₂ estimate established with reference to the IPCC emissions factor ID#110550. We take this as validation of our model, since this very slight discrepancy can be explained by our use of regional-standard fuels with differing NCVs, rounding errors, and the fact that we use molecular weights in our calculations that are defined out to five decimal places, compared to no decimal places as per the IPCC simplified method.

NOTE #65: Again, for the sake of comparison; when we draw upon a different series of emissions factors from the IPCC's 'Emission Factor Database' (EFDB); a series that is expressed in terms of grams of emissions per megajoule (g/MJ), and we perform essentially the same kind of calculations, we are pleased by the results. As we expected, there are significant differences between the results derived from this comparison, but this is explainable by the fact that the g/MJ emission factors are calculated with reference to a 'generic' jet aircraft, without reference to differing NCVs of aviation fuels, and without a stoichiometric balancing of carbon contents in the various gases. In this comparison; using EF ID #12126, we compute CO₂ emissions that are 100.686% of our model's result; using EF ID #18244, we compute CO emissions that are 63.714% of our model's result; using EF ID #119017,



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we compute NOx emissions that are 141.139% of our model's result; using EF ID #119014, we compute N2O emissions that are 89.2% of our model's result; using EF ID #18284, we compute NMVOC emissions that are 318.571% of our model's result; using EF ID #190, we compute SOx emissions that are 101.242% of our model's result; which seems reasonable, all things considered. This too, we take as validation of our model, since the emissions most dependent on fuel consumption are also the ones that come closest to 100% of our preferred estimates.

NOTE #66: Once more, for the sake of comparison; when we apply the guidelines of the United States 'Environmental Protection Agency' (EPA), published in "CLIMATE LEADERS — Greenhouse Gas Inventory Protocol Core Module Guidance: Direct Emissions from Mobile Combustion Sources"; we find that the 'fuel consumption method' for calculating emissions is favoured as the most accurate way to estimate emissions from freight transport. To this end, we have drawn upon the N2O and CH4 emission factors for jet fuel of 0.1 g/kg fuel used, and 0.087 g/kg fuel used, respectively, that are found in 'Table A-6: CH4 and N2O Emission Factors for Non-Highway Vehicles', on page 24. For a CO2 emission factor we turned to 'Table B-2: Factors for Calculating CO2 Emissions from Fuel Oil, Aviation Gasoline, and Jet Fuel Use', on page 27. This table notes an emission factor of 9.57 kg-CO2 per US Gallon of fuel used, which when factored by the fuel density value from Table A-6 of 3.08 kg/US Gallon, establishes a carbon dioxide emission factor of 3.107 kg-CO2 per kg of fuel (or 3,107 g-CO2/kg fuel). When we apply these US EPA emission factors to the jet kerosene fuel requirement we have established for this delivery, we arrived at the following results: Given the requirement for 0.047 kg of jet kerosene (0.015 US gallons) for *cruise-level* flight, the US EPA estimate for carbon dioxide would be 0.15 kg-CO2; for nitrous oxide would be 0.000005 kg-N2O, and for methane would be 0.000004 kg-CH4. Because the IPCC and EEA data sets we have relied on do not include methane emissions from aviation (as aviation is deemed an insignificant or non-existent source), we cannot compare the US EPA's estimate for methane to any of our figures. As for carbon dioxide, the EPA's estimate is 98.64% of our model's estimate (which we still prefer, as our CO2 estimate is stoichiometrically balanced); while the nitrous oxide estimate based on the EPA's factors is 100.00% of our model's estimate. On the whole, we take these calculations as further validation of our model and our methods.

NOTE #67: With this assurance in our model's calculations, we can turn our attention to rectifying the 'carbon balance' of our calculations. This is necessary because both of the default carbon dioxide emissions factors noted above assume 100% oxidation of the fuel. This means that the other carbonaceous emissions calculated by our analysis, namely carbon monoxide (CO), methane (CH4), and the non-methane volatile organic compounds (NMVOCs), will effectively count some carbon atoms twice. To avoid this error, we first calculated the CO2 emissions that would result from the complete combustion of the identified CO and CH4 emissions, and subtracted these sums from our carbon dioxide estimate. We then did the same thing for each one of the 82 organic gases identified in the US EPA/FAA's aviation emissions profile, which together account for 0.157 grams of CO2, and also subtracted this sum from our CO2 estimate.

NOTE #68: ALTOGETHER, as noted above; our analysis reveals that the transport of the 0.71 kg (1.56 Lb.) hard cover book (corrugated packaging included); flown from 'Detroit Metropolitan Wayne County Airport' in Detroit, to 'Chicago Midway International Airport' in Chicago; on board a 'Embraer RJ145EP (EMB-145EP)' fuelled by jet kerosene (of the IEA 2010 North American default specification), RESULTED IN THE FOLLOWING AIRBORNE EMISSIONS: 0.18 kg (0.4 Lb.) of carbon dioxide (CO2); 0.00047 kg (0.00105 Lb.) of carbon monoxide (CO); 0 kg (0 Lb.) of methane (CH4); 0.00045 kg (0.001 Lb.) of nitrogen oxides (NOx); 0.000006 kg (0.000013 Lb.) of nitrous oxide (N2O); 0.00005 kg (0.00011 Lb.) of non-methane organic compounds (NMVOCs); and 0.000058 kg (0.000127 Lb.) of sulphur oxides (SOx).

NOTE #69: Reference Notes RE: Emission factor found in the 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories' (Table 1-52 on Page 1.98) of the Reference Manual 'Default Emission factors and Fuel Consumption for Aircraft' (NB: LTO emission factors are given on a per-aircraft basis.) Worksheet 1-5; Sheet 3-3. This applies to international flights. Emission Factor Reported to EFDB: 3150 kg/t fuel (equivalent to 3150 g/kg fuel). Data Provider: IPCC. Data Provider Contact: ipcc-efdb@iges.or.jp

NOTE #70: Reference Notes RE: Emission factor found in the 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories' (Table 1-52 on Page 1.98) of the Reference Manual 'Default Emission factors and Fuel Consumption for Aircraft' (NB: LTO emission factors are given on a per-aircraft basis.) Worksheet 1-5; Sheet 3-3. This applies to domestic flights. Emission Factor Reported to EFDB: 7 kg/t fuel (equivalent to 7 g/kg fuel). Data Provider: IPCC. Data Provider Contact: ipcc-efdb@iges.or.jp

NOTE #71: Reference Notes RE: Emission factor found in the 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories' (Table 1-52 on Page 1.98) of the Reference Manual 'Default Emission factors and Fuel Consumption for Aircraft' (NB: LTO emission factors are given on a per-aircraft basis.) Worksheet 1-5; Sheet 3-3. This applies to international flights. Studies indicate that during cruise no methane is emitted. Emission Factor Reported to EFDB: 0 kg/t fuel (equivalent to 0 g/kg fuel). Data Provider: IPCC. Data Provider Contact: ipcc-efdb@iges.or.jp



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NOTE #72: Reference Notes RE: Emission factor found in IPCC Guidelines indicating 7.9 g NO_x emissions per kg fuel used in the regional jet 'ERJ-145'. Data Source: '2006 IPCC Guidelines for National Greenhouse Gas Inventories', Volume 2, Energy; Chapter 3, Mobile Combustion; Table 3.6.10; Nox Emission Factors for Various Aircraft at Cruise Levels; Page 3.72, IN REFERENCE TO: Sutkus, D.J., Baughcum, S.L., DuBois, D.P.,(2001) 'Scheduled civil aircraft emission inventories for 1999: database development and Analysis.' NASA/CR—2001-211216, National Aeronautics and Space Administration, Glenn Research Center, USA, October 2001.

NOTE #73: Reference Notes RE: Emission factor found in the 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories' (Table 1-52 on Page 1.98) of the Reference Manual 'Default Emission factors and Fuel Consumption for Aircraft' (NB: LTO emission factors are given on a per-aircraft basis.) Worksheet 1-5; Sheet 3-3. This applies to domestic flights. Estimates are based on Tier 1 default values. Emission Factor Reported to EFDB: 0.1 kg/t fuel (equivalent to 0.1 g/kg fuel). Data Provider: IPCC. Data Provider Contact: ipcc-efdb@iges.or.jp

NOTE #74: Reference Notes RE: Emission factor found in the 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories' (Table 1-52 on Page 1.98) of the Reference Manual 'Default Emission factors and Fuel Consumption for Aircraft' (NB: LTO emission factors are given on a per-aircraft basis.) Worksheet 1-5; Sheet 3-3. This applies to domestic flights. Studies indicate that no methane is emitted during cruise. Emission Factor Reported to EFDB: 0.7 kg/t fuel (equivalent to 0.7 g/kg fuel). Data Provider: IPCC. Data Provider Contact: ipcc-efdb@iges.or.jp

NOTE #75: Reference Notes RE: Emission factor found in the 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories' (Table 1-52 on Page 1.98) of the Reference Manual 'Default Emission factors and Fuel Consumption for Aircraft' (NB: LTO emission factors are given on a per-aircraft basis.) Worksheet 1-5; Sheet 3-3. This applies to domestic flights. Sulphur content of the fuel is assumed to be 0.05% for both LTO and cruise activities. Emission Factor Reported to EFDB: 1 kg/t fuel (equivalent to 1 g/kg fuel). Data Provider: IPCC. Data Provider Contact: ipcc-efdb@iges.or.jp

NOTE #76: Reference Notes RE: IPCC Emission Factor ID #12126 for jet kerosene-fuelled generic civilian jet aircraft-borne freight, emitting carbon dioxide at the rate of 71590.0000 g/GJ (equivalent to 71.59 g/MJ); with applicability as Europe / EEA / CITEPA default. Source data from CORINAIR 94. Data Provider: EEA/CITEPA.

NOTE #77: Reference Notes RE: IPCC Emission Factor ID #18244 for jet kerosene-fuelled generic civilian jet aircraft-borne freight, emitting carbon monoxide at the rate of 100 KG/TJ (equivalent to 0.1 g/MJ); with applicability as 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-10 on Page 1.40 of the Reference Manual). IPCC Worksheet 1-3; Sheet 2 - 3. Data Provider: IPCC. Data Provider Comments: The following default emission factors have been developed by the IPCC based on CORINAIR90 among others. These factors are considered the best available global default factors to date. Data provider email: ipcc-efdb@iges.or.jp

NOTE #78: Reference Notes RE: IPCC Emission Factor ID #18124 for jet kerosene-fuelled generic civilian jet aircraft-borne freight, emitting methane at the rate of 0.5 KG/TJ (equivalent to 0.0005 g/MJ); with applicability as 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-7 on Page 1.35 of the Reference Manual). IPCC Worksheet 1-3; Sheet 2 - 3. Data Provider: IPCC. Data Provider Comments: These factors are considered the best available global default factors to date. Data provider email: ipcc-efdb@iges.or.jp

NOTE #79: Reference Notes RE: IPCC Emission Factor ID #119017 for jet kerosene-fuelled generic jet aircraft-borne freight, emitting nitrogen oxides (NO+NO₂) at the rate of 250 kg/TJ (equivalent to 0.25 g/MJ); with application as 2006 IPCC Global Default. Data reported to EFDB: nitrogen oxides (NO+NO₂) emissions of 250 kg/TJ (kg/TJ). Data source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy, Table 3.6.5; Equation 3.6.1. Technical Reference: Expert judgement by the authors of Section 3.6, Volume 2 of the 2006 IPCC Guidelines. Confidence limits: Upper: +25%, Lower: -25%. NB: Tier 1 assumes that all aircraft have the same emission factors based on the rate of fuel consumption.

NOTE #80: Reference Notes RE: IPCC Emission Factor ID #119014 for jet kerosene-fuelled generic jet aircraft-borne freight, emitting nitrous oxide at the rate of 2 kg/TJ (equivalent to 0.002 g/MJ); with application as 2006 IPCC Global Default. Data reported to EFDB: NITROUS OXIDE emissions of 2 kg/TJ (kg/TJ). Data source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy, Table 3.6.5; Equation 3.6.1. IPCC Worksheet: 1A, Sheet 1 of 4 (page A1.6) in Annex 1 of Volume 2. Technical Reference: IPCC (1999). "Aviation and the global atmosphere." Eds: Penner, J.E., Lister, D.H., Griggs, D.J., Dokken, D.J., McFarland, M., Intergovernmental Panel on Climate Change, Cambridge University Press 1999. Confidence limits: Upper: +150%, Lower: -70%. NB: Tier 1 assumes that all aircraft have the same emission factors based on the rate of fuel consumption.



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NOTE #81: Reference Notes RE: IPCC Emission Factor ID #18284 for jet kerosene-fuelled generic civilian jet aircraft-borne freight, emitting non methane volatile organic compounds at the rate of 50 KG/TJ (equivalent to 0.05 g/MJ); with applicability as 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-11 on Page 1.42 of the Reference Manual). IPCC Worksheet 1-3; Sheet 2 - 3. Data Provider: IPCC. Data Provider Comments: The following default emission factors have been developed by the IPCC based on CORINAIR90 among others. This emission factor is for jet kerosene. The emission factor for aviation gasoline is 300kg/TJ. Data provider email: ipcc-efdb@iges.or.jp

NOTE #82: Reference Notes RE: IPCC Emission Factor ID #190 for jet kerosene-fuelled generic jet aircraft-borne freight, emitting sulphur dioxides (SO₂+SO₃) at the rate of 22.7000 g/GJ (equivalent to 0.0227 g/MJ); with application as European EEA/CITEPA Default. Data reported to EFDB: SULPHUR DIOXIDE (SO₂+SO₃) emissions of 22.7000 g/GJ . Data source: CORINAIR 94.

NOTE #83: Reference Notes RE: the CORINAIR data used to estimate emissions due to the landing-and-takeoff (LTO) cycle; with a fuel requirement and emissions profile specific to a 'Embraer 110P2A', used to model LTO-cycle emissions for a flight of between 231.5 km and 463 km. (This aircraft was deemed to be a representative proxy for a 'Embraer ERJ145'.) To do this, we calculated the ratios for the fuel requirement, and NO_x, HC and CO emissions for the 'climb-cruise-descent' (CCD) phase of flight, 'over' the 'landing-and-takeoff' (LTO) cycle; then used this ratio to estimate LTO-cycle emissions, factoring against our estimates for cruise-level emissions, which are based on IPCC and EEA emissions factors. For fuel, this aircraft flying this distance used 224.7 kg during CCD and 48.9 kg during LTO; for a ratio of LTO/CCD = 0.21762. For NO_x, this aircraft emitted 1.309 kg during CCD and 0.276 kg during LTO; for a ratio of LTO/CCD = 0.21085. For hydrocarbons, this aircraft emitted 48.6 kg during CCD and 24.4 kg during LTO; for a ratio of LTO/CCD = 0.50206. For carbon monoxide, this aircraft emitted 869.2 kg during CCD and 371.4 kg during LTO; for a ratio of LTO/CCD = 0.42729. We applied the fuel use ratio to our CO₂ and SO_x estimates, the NO_x ratio was applied to our NO_x and N₂O estimates, the HC ratio was applied to our CH₄ and NMVOC estimates, and the CO ratio was applied to our CO estimates. These derived LTO estimates were aggregated with our CCD estimates, then stoichiometrically balanced in our model, as explained above. The CORINAIR data set is available online from www.eea.europa.eu.

NOTE #84: Reference Notes RE: the emissions factors drawn from the United States 'Environmental Protection Agency', Office of Air and Radiation: 'CLIMATE LEADERS – Greenhouse Gas Inventory Protocol Core Module Guidance, Direct Emissions from Mobile Combustion Sources' (EPA430-K-08-004), available online at www.epa.gov/climateleaders.

NOTE #85: Delivery Leg 4 of 5 from: Chicago Midway International Airport, IATA Airport Code MDW, Chicago, USA; to: Kansas City International Airport, IATA Airport Code MCI, Kansas City, USA. This involves the further transport of the same package, a distance of 709.1 km (382.9 miles), establishing a 'workload' for this leg of 0.500 metric-tonne kilometres. After factoring for the energy requirements of the 'Boeing 737-700' we modelled for, the need for 3,753 kilojoules of energy is established, which is the fuel equivalent of 0.084 kg of jet kerosene (assuming an NCV of 44,600 KJ/kg). By applying the '2006 IPCC Guidelines for National Greenhouse Gas Inventories'; but using an even more precise method than the one suggested there; we calculated our 'base carbon dioxide emissions' using a CO₂ intensity factor of 71 mg CO₂ per kilojoule of fuel combusted (at 100% oxidation). We also drew on a select panel of emissions factors to model other emissions, including; carbon monoxide (CO), methane (CH₄), nitrogen oxides (NO+NO₂), nitrous oxide (N₂O), and non-methane volatile organic compounds (NMVOCs). Because the CO, CH₄ and NMVOCs all contain carbon, we then reduced our 'base CO₂ estimate' to bring all of our emissions estimates into 'stoichiometric balance'.

NOTE #86: This airborne leg for the delivery of the 0.71 kg (1.56 Lb.) hard cover book (corrugated packaging included); with delivery from 'Chicago Midway International Airport' in Chicago, to 'Kansas City International Airport' in Kansas City; a flight of 709 km (383 nautical miles) based on the straight-line 'great circle' distance, plus a 9% 'uplift factor' as per IPCC guidelines (available online at <http://www.ipcc.ch/ipccreports/sres/aviation/121.htm#8223>); on board a 'Boeing 737-700' fuelled by jet kerosene (of the IEA 2010 North American default specification); would require an estimated 0.08 kg of jet kerosene during cruise-level flight, and an estimated 0.02 kg during the take-off and landing (0.19 Lbs. and 0.05 Lbs., respectively).

NOTE #87: The combustion of this quantity of this fuel in this aircraft operating under these conditions, will result in the following airborne emissions; 0.34 kg (0.76 Lbs.) of carbon dioxide; 0.0018 kg (0.004 Lbs.) of carbon monoxide; 0 kg (0 Lbs.) of methane; 0.0013 kg (0.003 Lbs.) of nitrogen oxides (NO+NO₂); 0.000011 kg (0.000024 Lbs.) of nitrous oxide (N₂O); 0.00018 kg (0.00039 Lbs.) of non-methane volatile organic compounds (NMVOCs); and 0.00011 kg (0.00024 Lbs.) of sulphur oxides (SO₂+SO₃) emissions.

NOTE #88: With reliance on research performed by the 'Environmental Protection Agency' and the 'Federal Aviation Administration' in the United States; we can estimate the organic gas constituents that make up the NMVOC emissions, including: 30.3 mg of ethylene; 28.6 mg of C-10 paraffins; 24.1 mg of formaldehyde; 11.5 mg of C-10 olefins (modeled as trans-3,trans-6-decadiene);



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11.5 mg of decanal; 8.89 mg of propylene; 8.38 mg of acetaldehyde; 7.72 mg of acetylene; 5.73 mg of 2-dodecenal; 4.80 mg of acrolein; 3.56 mg of glyoxal; 3.54 mg of methanol; 3.44 mg of isobutene/1-butene; 3.31 mg of 1,3-butadiene; 3.30 mg of benzene; 2.95 mg of methylglyoxal; 2.03 mg of crotonaldehyde; 1.52 mg of 1-pentene; 1.44 mg of 1-hexene; 1.43 mg of propionaldehyde; 1.42 mg of phenol; 1.29 mg of c4-benzene + c3-aroald; 1.26 mg of toluene; 1.06 mg of naphthalene; 1.05 mg of n-tridecane; 1.02 mg of ethane; 0.922 mg of benzaldehyde; 0.906 mg of n-dodecane; 0.871 mg of n-undecane; 0.859 mg of 1-heptene; 0.841 mg of methacrolein; 0.816 mg of n-tetradecane; 0.800 mg of 2-methylpentane; 0.724 mg of acetone; 0.704 mg of trans-2-pentene; 0.686 mg of 1,2,4-trimethylbenzene; 0.635 mg of c5-benzene + c4-aroald; 0.627 mg of n-decane; 0.606 mg of styrene; 0.545 mg of m-tolualdehyde; 0.541 mg of cis-2-pentene; 0.541 mg of 1-octene; 0.484 mg of 1-methyl naphthalene; 0.482 mg of 1-nonene; 0.480 mg of valeraldehyde; 0.451 mg of o-tolualdehyde; 0.412 mg of cis-2-butene; 0.404 mg of 2-methyl-naphthalene; 0.388 mg of n-pentane; 0.365 mg of c14-alkane (modeled as N-tetradecane); 0.363 mg of 1-decene; 0.363 mg of 2-methyl-2-butene; 0.347 mg of c15-alkane (modeled as N-pentadecane); 0.341 mg of ethylbenzene; 0.339 mg of n-pentadecane; 0.325 mg of o-xylene; 0.302 mg of m-ethyltoluene; 0.286 mg of c16-alkane (modeled as N-hexadecane); 0.276 mg of m-xylene; 0.276 mg of p-xylene; 0.275 mg of 2-methyl-1-butene; 0.233 mg of butyraldehyde; 0.220 mg of 3-methyl-1-butene; 0.208 mg of 1,2,3-trimethylbenzene; 0.176 mg of 2,6-dimethylnaphthalene; 0.153 mg of propane; 0.135 mg of 4-methyl-1-pentene; 0.127 mg of o-ethyltoluene; 0.125 mg of p-ethyltoluene; 0.125 mg of n-heptane; 0.122 mg of n-nonane; 0.122 mg of n-octane; 0.106 mg of 1,3,5-trimethylbenzene; 0.104 mg of n-propylbenzene; 0.096 mg of n-hexadecane; 0.094 mg of p-tolualdehyde; 0.067 mg of 2-methyl-1-pentene; 0.063 mg of isovaleraldehyde; 0.059 mg of trans-2-hexene; 0.018 mg of n-heptadecane; 0.006 mg of isopropylbenzene; and 0.004 mg of c18-alkane (modeled as N-octadecane).

NOTE #89: By applying the US EPA and FAA's "Recommended Best Practice for Quantifying Speciated Organic Gas Emissions from Aircraft Equipped with Turbofan, Turbojet, and Turboprop Engines, Version 1.0"; we were able to perform a 'carbon mass balance' calculation to ensure that no 'double counting' entered our estimates. At their foundations, our estimates are based on the following data points FOR CRUISE-LEVEL FLIGHT; for carbon dioxide we drew upon IPCC Emission Factor ID #110550 which establishes a rate of emissions of 3150 kg/tonne fuel (Jet Kerosene) burned in a Jet Aircraft (Generic); for carbon monoxide we drew upon IPCC Emission Factor ID #110541 which establishes a rate of emissions of 7 kg/tonne fuel (Jet Kerosene) burned in a Jet Aircraft (Generic); for methane we drew upon IPCC Emission Factor ID #110553 which establishes a rate of emissions of 0 kg/tonne fuel (Jet Kerosene) burned in a Jet Aircraft (Generic); for nitrogen oxides (NO+NO₂) we drew upon the 2006 IPCC Volume 2, Chapter 3, Table 3.6.10 Boeing 737-700 jet aircraft emission factor for NO_x which establishes a rate of emissions of 12.4 g/kg (Jet Kerosene) burned in a Jet Aircraft - 737-700; for nitrous oxide we drew upon IPCC Emission Factor ID #110535 which establishes a rate of emissions of 0.1 kg/tonne fuel (Jet Kerosene) burned in a Jet Aircraft (Generic); for non methane volatile organic compounds we drew upon IPCC Emission Factor ID #110544 which establishes a rate of emissions of 0.7 kg/tonne fuel (Jet Kerosene) burned in a Jet Aircraft (Generic); and for sulphur dioxides (SO₂+SO₃) we drew upon IPCC Emission Factor ID #110547 which establishes a rate of emissions of 1 kg/tonne fuel (Jet Kerosene) burned in a Jet Aircraft (Generic).

NOTE #90: To calculate fuel requirements, a number of factors were considered. First was the weight of the 0.71 kg (1.56 Lb.) hard cover book (including corrugated packaging), and the fact that it was flown from 'Chicago Midway International Airport' in Chicago, to 'Kansas City International Airport' in Kansas City; a flight of 709 km (383 nautical miles). This establishes a workload of 0.50 metric tonne-kilometres, which when factored against the 7.5 MJ/tonne-km energy intensity factor, as published by Michael Landwehr and Céline Marie-Lilliu of the 'International Energy Agency' in 'Transportation Projections in OECD Regions, Detailed Report, May 2002'; Appendix 3, page 155, specific to North America, 2010 fleet (reported as 7.5 MJ/tonne-km of freight); establishes an energy requirement of 3,753 KJ.

NOTE #91: Because we modelled 'Jet Kerosene of the IEA 2010 North American Default' quality as the fuel for this flight, and because this fuel has a 'net calorific value' of 44,600 KJ/kg, we were able to calculate a fuel requirement for cruise-level flight of 0.084 kg (0.186 Lbs.). This quantity of fuel, factored against the emissions factors listed below, establishes the CO₂, CO, CH₄, NO+NO₂, N₂O, NMVOC and SO₂+SO₃ emissions stemming from cruise-level flight.

NOTE #92: We then used the 'European Environment Agency' (EEA), 'European Monitoring and Evaluation Programme' (EMEP) data set known as 'CORINAIR' to model emissions during the landing and take-off (LTO) cycle. This involved selecting a representative aircraft from the CORINAIR data set that was comparable to the 'Boeing 737-700' modelled for this flight; in this case the 'B737 400'. Unlike the aforementioned factors used to calculate cruise-level emissions, which establish emissions rates on a fuel usage basis; the CORINAIR data pertains to whole-aircraft fuel requirements and emissions. The CORINAIR data distinguishes between flight operations above an altitude of 914 M, termed 'climb-cruise-descent' (CCD), and operations below 914 M, termed 'landing and take-off' (LTO). This permitted the calculation of ratios, specific to a flight of between 463 km and 926 km, which enabled us to simulate fuel requirements and emissions during the LTO cycle, by factoring against our cruise-level estimates.



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NOTE #93: To do this, we applied the fuel consumption ratio we observed in the CORINAIR data set for a 'B737 400' flying between 463 km and 926 km, to model an LTO fuel requirement equal to 0.296 that of the CCD fuel requirement. This same ratio was also applied to *preliminary* CO₂ emissions estimates and also to sulphur oxides emissions estimates, as these aspects of emissions are highly dependent on fuel consumption. We used the CORINAIR ratio of 0.288 for nitrogen oxides emissions (LTO/CCD), to estimate NO_x and N₂O emissions during LTO, in similar fashion. The CORINAIR ratio of 2.026 for hydrocarbons emissions (also LTO/CCD, of course), was factored against cruise level emissions estimates for NMVOCs and also for methane (CH₄) emissions, although, the base estimate for CH₄ emissions was zero. The CORINAIR ratio of 2.078 for carbon monoxide was applied to the CCD CO emissions estimate in order to derive CO emissions during LTO. Altogether, these estimates for CCD and LTO emissions were aggregated to establish 'whole flight' emissions.

NOTE #94: At this point in our calculations, we focused our attention directly on the carbon dioxide estimates, which constitute the overwhelming bulk of the greenhouse gas emissions from aviation. Our model approaches this calculation from two different angles. In the first case, we multiplied the 0.50 MT-km workload by the 7.5 MJ/MT-km energy intensity factor published by Michael Landwehr and Céline Marie-Lilliu of the 'International Energy Agency' in 'Transportation Projections in OECD Regions, Detailed Report, May 2002'; Appendix 3, page 155, specific to North America, 2010 fleet (reported as 7.5 MJ/tonne-km of freight); for air cargo. Further multiplying the product of this calculation by 1000 establishes the kilojoules requirement for fuel (i.e. 3,753 KJ). When we divide this KJ requirement for fuel by the 'net calorific value' of the IPCC 2006 'default' grade of jet kerosene (which is 44,100 KJ/kg), we arrive at a fuel requirement of 0.09 kg. When this amount of fuel is factored against the aforementioned IPCC Emission Factor ID #110550 which establishes a rate of emissions of 3150 kg/tonne fuel (or 3150 g/kg fuel), we find that 0.09 kg fuel * 3150 g CO₂/kg fuel = 0.27 kg CO₂ from cruise-level flight.

NOTE #95: For the sake of comparison; when we multiply this same energy requirement for fuel of 3,753 KJ, by the fuel-type specific carbon dioxide emissions factor of 0.000071452 kg CO₂/KJ, based on the '2006 IPCC Guidelines for National Greenhouse Gas Inventories' (Volume 2, Energy; Chapter 1, Introduction; Table 1.4; Pages 1.23 - 1.24); EXCEPT that we perform the full-fledged scientific calculation, such that 'Jet Kerosene', with a default carbon content of 19.5 kg/GJ, when subject to 100% oxidation, and factored for the full molecular weights of CO₂/C (44.00945 / 12.01065), results in 71,452 kg CO₂/TJ; we thus arrive at 0.27 kg CO₂ from cruise-level flight, when we specify the use of jet kerosene of the 'IEA 2010 North American Default' standard. This figure is 101.167% of the CO₂ estimate established with reference to the IPCC emissions factor ID#110550. We take this as validation of our model, since this very slight discrepancy can be explained by our use of regional-standard fuels with differing NCVs, rounding errors, and the fact that we use molecular weights in our calculations that are defined out to five decimal places, compared to no decimal places as per the IPCC simplified method.

NOTE #96: Again, for the sake of comparison; when we draw upon a different series of emissions factors from the IPCC's 'Emission Factor Database' (EFDB); a series that is expressed in terms of grams of emissions per megajoule (g/MJ), and we perform essentially the same kind of calculations, we are pleased by the results. As we expected, there are significant differences between the results derived from this comparison, but this is explainable by the fact that the g/MJ emission factors are calculated with reference to a 'generic' jet aircraft, without reference to differing NCVs of aviation fuels, and without a stoichiometric balancing of carbon contents in the various gases. In this comparison; using EF ID #12126, we compute CO₂ emissions that are 101.185% of our model's result; using EF ID #18244, we compute CO emissions that are 63.714% of our model's result; using EF ID #119017, we compute NO_x emissions that are 89.919% of our model's result; using EF ID #119014, we compute N₂O emissions that are 89.2% of our model's result; using EF ID #18284, we compute NMVOC emissions that are 318.571% of our model's result; using EF ID #190, we compute SO_x emissions that are 101.242% of our model's result; which seems reasonable, all things considered. This too, we take as validation of our model, since the emissions most dependent on fuel consumption are also the ones that come closest to 100% of our preferred estimates.

NOTE #97: Once more, for the sake of comparison; when we apply the guidelines of the United States 'Environmental Protection Agency' (EPA), published in "CLIMATE LEADERS — Greenhouse Gas Inventory Protocol Core Module Guidance: Direct Emissions from Mobile Combustion Sources"; we find that the 'fuel consumption method' for calculating emissions is favoured as the most accurate way to estimate emissions from freight transport. To this end, we have drawn upon the N₂O and CH₄ emission factors for jet fuel of 0.1 g/kg fuel used, and 0.087 g/kg fuel used, respectively, that are found in 'Table A-6: CH₄ and N₂O Emission Factors for Non-Highway Vehicles', on page 24. For a CO₂ emission factor we turned to 'Table B-2: Factors for Calculating CO₂ Emissions from Fuel Oil, Aviation Gasoline, and Jet Fuel Use', on page 27. This table notes an emission factor of 9.57 kg-CO₂ per US Gallon of fuel used, which when factored by the fuel density value from Table A-6 of 3.08 kg/US Gallon, establishes a carbon dioxide emission factor of 3.107 kg-CO₂ per kg of fuel (or 3,107 g-CO₂/kg fuel). When we apply these US EPA emission factors to the jet kerosene fuel requirement we have established for this delivery, we arrived at the following results: Given the requirement for 0.084 kg of jet kerosene (0.027 US gallons) for *cruise-level* flight, the US EPA estimate for carbon dioxide would be 0.26 kg-CO₂; for nitrous oxide would be 0.000008 kg-N₂O, and for methane would be 0.000007 kg-CH₄. Because the IPCC and EEA data sets

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we have relied on do not include methane emissions from aviation (as aviation is deemed an insignificant or non-existent source), we cannot compare the US EPA's estimate for methane to any of our figures. As for carbon dioxide, the EPA's estimate is 98.64% of our model's estimate (which we still prefer, as our CO₂ estimate is stoichiometrically balanced); while the nitrous oxide estimate based on the EPA's factors is 100.00% of our model's estimate. On the whole, we take these calculations as further validation of our model and our methods.

NOTE #98: With this assurance in our model's calculations, we can turn our attention to rectifying the 'carbon balance' of our calculations. This is necessary because both of the default carbon dioxide emissions factors noted above assume 100% oxidation of the fuel. This means that the other carbonaceous emissions calculated by our analysis, namely carbon monoxide (CO), methane (CH₄), and the non-methane volatile organic compounds (NMVOCs), will effectively count some carbon atoms twice. To avoid this error, we first calculated the CO₂ emissions that would result from the complete combustion of the identified CO and CH₄ emissions, and subtracted these sums from our carbon dioxide estimate. We then did the same thing for each one of the 82 organic gases identified in the US EPA/FAA's aviation emissions profile, which together account for 0.560 grams of CO₂, and also subtracted this sum from our CO₂ estimate.

NOTE #99: ALTOGETHER, as noted above; our analysis reveals that the transport of the 0.71 kg (1.56 Lb.) hard cover book (corrugated packaging included); flown from 'Chicago Midway International Airport' in Chicago, to 'Kansas City International Airport' in Kansas City; on board a 'Boeing 737-700' fuelled by jet kerosene (of the IEA 2010 North American default specification), RESULTED IN THE FOLLOWING AIRBORNE EMISSIONS: 0.34 kg (0.76 Lb.) of carbon dioxide (CO₂); 0.0018 kg (0.004 Lb.) of carbon monoxide (CO); 0 kg (0 Lb.) of methane (CH₄); 0.0013 kg (0.003 Lb.) of nitrogen oxides (NO_x); 0.000011 kg (0.000024 Lb.) of nitrous oxide (N₂O); 0.00018 kg (0.00039 Lb.) of non-methane organic compounds (NMVOCs); and 0.00011 kg (0.00024 Lb.) of sulphur oxides (SO_x).

NOTE #100: Reference Notes RE: Emission factor found in the 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories' (Table 1-52 on Page 1.98) of the Reference Manual 'Default Emission factors and Fuel Consumption for Aircraft' (NB: LTO emission factors are given on a per-aircraft basis.) Worksheet 1-5; Sheet 3-3. This applies to international flights. Emission Factor Reported to EFDB: 3150 kg/t fuel (equivalent to 3150 g/kg fuel). Data Provider: IPCC. Data Provider Contact: ipcc-efdb@iges.or.jp

NOTE #101: Reference Notes RE: Emission factor found in the 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories' (Table 1-52 on Page 1.98) of the Reference Manual 'Default Emission factors and Fuel Consumption for Aircraft' (NB: LTO emission factors are given on a per-aircraft basis.) Worksheet 1-5; Sheet 3-3. This applies to domestic flights. Emission Factor Reported to EFDB: 7 kg/t fuel (equivalent to 7 g/kg fuel). Data Provider: IPCC. Data Provider Contact: ipcc-efdb@iges.or.jp

NOTE #102: Reference Notes RE: Emission factor found in the 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories' (Table 1-52 on Page 1.98) of the Reference Manual 'Default Emission factors and Fuel Consumption for Aircraft' (NB: LTO emission factors are given on a per-aircraft basis.) Worksheet 1-5; Sheet 3-3. This applies to international flights. Studies indicate that during cruise no methane is emitted. Emission Factor Reported to EFDB: 0 kg/t fuel (equivalent to 0 g/kg fuel). Data Provider: IPCC. Data Provider Contact: ipcc-efdb@iges.or.jp

NOTE #103: Reference Notes RE: Emission factor found in IPCC Guidelines indicating 12.4 g NO_x emissions per kg fuel used in the large commercial aircraft '737-700'. Data Source: '2006 IPCC Guidelines for National Greenhouse Gas Inventories', Volume 2, Energy; Chapter 3, Mobile Combustion; Table 3.6.10; Nox Emission Factors for Various Aircraft at Cruise Levels; Page 3.72, IN REFERENCE TO: Sutkus, D.J., Baughcum, S.L., DuBois, D.P.,(2001) 'Scheduled civil aircraft emission inventories for 1999: database development and Analysis.' NASA/CR—2001-211216, National Aeronautics and Space Administration, Glenn Research Center, USA, October 2001.

NOTE #104: Reference Notes RE: Emission factor found in the 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories' (Table 1-52 on Page 1.98) of the Reference Manual 'Default Emission factors and Fuel Consumption for Aircraft' (NB: LTO emission factors are given on a per-aircraft basis.) Worksheet 1-5; Sheet 3-3. This applies to domestic flights. Estimates are based on Tier 1 default values. Emission Factor Reported to EFDB: 0.1 kg/t fuel (equivalent to 0.1 g/kg fuel). Data Provider: IPCC. Data Provider Contact: ipcc-efdb@iges.or.jp

NOTE #105: Reference Notes RE: Emission factor found in the 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories' (Table 1-52 on Page 1.98) of the Reference Manual 'Default Emission factors and Fuel Consumption for Aircraft' (NB: LTO emission factors are given on a per-aircraft basis.) Worksheet 1-5; Sheet 3-3. This applies to domestic flights. Studies indicate

that no methane is emitted during cruise. Emission Factor Reported to EFDB: 0.7 kg/t fuel (equivalent to 0.7 g/kg fuel). Data Provider: IPCC. Data Provider Contact: ipcc-efdb@iges.or.jp

NOTE #106: Reference Notes RE: Emission factor found in the 'Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories' (Table 1-52 on Page 1.98) of the Reference Manual 'Default Emission factors and Fuel Consumption for Aircraft' (NB: LTO emission factors are given on a per-aircraft basis.) Worksheet 1-5; Sheet 3-3. This applies to domestic flights. Sulphur content of the fuel is assumed to be 0.05% for both LTO and cruise activities. Emission Factor Reported to EFDB: 1 kg/t fuel (equivalent to 1 g/kg fuel). Data Provider: IPCC. Data Provider Contact: ipcc-efdb@iges.or.jp

NOTE #107: Reference Notes RE: IPCC Emission Factor ID #12126 for jet kerosene-fuelled generic civilian jet aircraft-borne freight, emitting carbon dioxide at the rate of 71590.0000 g/GJ (equivalent to 71.59 g/MJ); with applicability as Europe / EEA / CITEPA default. Source data from CORINAIR 94. Data Provider: EEA/CITEPA.

NOTE #108: Reference Notes RE: IPCC Emission Factor ID #18244 for jet kerosene-fuelled generic civilian jet aircraft-borne freight, emitting carbon monoxide at the rate of 100 KG/TJ (equivalent to 0.1 g/MJ); with applicability as 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-10 on Page 1.40 of the Reference Manual). IPCC Worksheet 1-3; Sheet 2 - 3. Data Provider: IPCC. Data Provider Comments: The following default emission factors have been developed by the IPCC based on CORINAIR90 among others. These factors are considered the best available global default factors to date. Data provider email: ipcc-efdb@iges.or.jp

NOTE #109: Reference Notes RE: IPCC Emission Factor ID #18124 for jet kerosene-fuelled generic civilian jet aircraft-borne freight, emitting methane at the rate of 0.5 KG/TJ (equivalent to 0.0005 g/MJ); with applicability as 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-7 on Page 1.35 of the Reference Manual). IPCC Worksheet 1-3; Sheet 2 - 3. Data Provider: IPCC. Data Provider Comments: These factors are considered the best available global default factors to date. Data provider email: ipcc-efdb@iges.or.jp

NOTE #110: Reference Notes RE: IPCC Emission Factor ID #119017 for jet kerosene-fuelled generic jet aircraft-borne freight, emitting nitrogen oxides (NO+NO₂) at the rate of 250 kg/TJ (equivalent to 0.25 g/MJ); with application as 2006 IPCC Global Default. Data reported to EFDB: nitrogen oxides (NO+NO₂) emissions of 250 kg/TJ (kg/TJ). Data source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy, Table 3.6.5; Equation 3.6.1. Technical Reference: Expert judgement by the authors of Section 3.6, Volume 2 of the 2006 IPCC Guidelines. Confidence limits: Upper: +25%, Lower: -25%. NB: Tier 1 assumes that all aircraft have the same emission factors based on the rate of fuel consumption.

NOTE #111: Reference Notes RE: IPCC Emission Factor ID #119014 for jet kerosene-fuelled generic jet aircraft-borne freight, emitting nitrous oxide at the rate of 2 kg/TJ (equivalent to 0.002 g/MJ); with application as 2006 IPCC Global Default. Data reported to EFDB: NITROUS OXIDE emissions of 2 kg/TJ (kg/TJ). Data source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy, Table 3.6.5; Equation 3.6.1. IPCC Worksheet: 1A, Sheet 1 of 4 (page A1.6) in Annex 1 of Volume 2. Technical Reference: IPCC (1999). "Aviation and the global atmosphere." Eds: Penner, J.E., Lister, D.H., Griggs, D.J., Dokken, D.J., McFarland, M., Intergovernmental Panel on Climate Change, Cambridge University Press 1999. Confidence limits: Upper: +150%, Lower: -70%. NB: Tier 1 assumes that all aircraft have the same emission factors based on the rate of fuel consumption.

NOTE #112: Reference Notes RE: IPCC Emission Factor ID #18284 for jet kerosene-fuelled generic civilian jet aircraft-borne freight, emitting non methane volatile organic compounds at the rate of 50 KG/TJ (equivalent to 0.05 g/MJ); with applicability as 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-11 on Page 1.42 of the Reference Manual). IPCC Worksheet 1-3; Sheet 2 - 3. Data Provider: IPCC. Data Provider Comments: The following default emission factors have been developed by the IPCC based on CORINAIR90 among others. This emission factor is for jet kerosene. The emission factor for aviation gasoline is 300kg/TJ. Data provider email: ipcc-efdb@iges.or.jp

NOTE #113: Reference Notes RE: IPCC Emission Factor ID #190 for jet kerosene-fuelled generic jet aircraft-borne freight, emitting sulphur dioxides (SO₂+SO₃) at the rate of 22.7000 g/GJ (equivalent to 0.0227 g/MJ); with application as European EEA/CITEPA Default. Data reported to EFDB: SULPHUR DIOXIDE (SO₂+SO₃) emissions of 22.7000 g/GJ . Data source: CORINAIR 94.

NOTE #114: Reference Notes RE: the CORINAIR data used to estimate emissions due to the landing-and-takeoff (LTO) cycle; with a fuel requirement and emissions profile specific to a 'B737 400', used to model LTO-cycle emissions for a flight of between 463 km and 926 km. (This aircraft was deemed to be a representative proxy for a 'Boeing 737-700'.) To do this, we calculated the ratios for the fuel requirement, and NO_x, HC and CO emissions for the 'climb-cruise-descent' (CCD) phase of flight, 'over' the 'landing-and-takeoff' (LTO) cycle; then used this ratio to estimate LTO-cycle emissions, factoring against our estimates for cruise-level



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emissions, which are based on IPCC and EEA emissions factors. For fuel, this aircraft flying this distance used 2787.43989396017 kg during CCD and 825.387557446809 kg during LTO; for a ratio of LTO/CCD = 0.29611. For NO_x, this aircraft emitted 28.6351443736806 kg during CCD and 8.25474477509578 kg during LTO; for a ratio of LTO/CCD = 0.28827. For hydrocarbons, this aircraft emitted 329.050075546327 kg during CCD and 666.77776042067 kg during LTO; for a ratio of LTO/CCD = 2.02637. For carbon monoxide, this aircraft emitted 5694.58764929442 kg during CCD and 11830.9141069593 kg during LTO; for a ratio of LTO/CCD = 2.07757. We applied the fuel use ratio to our CO₂ and SO_x estimates, the NO_x ratio was applied to our NO_x and N₂O estimates, the HC ratio was applied to our CH₄ and NMVOC estimates, and the CO ratio was applied to our CO estimates. These derived LTO estimates were aggregated with our CCD estimates, then stoichiometrically balanced in our model, as explained above. The CORINAIR data set is available online from www.eea.europa.eu.

NOTE #115: Reference Notes RE: the emissions factors drawn from the United States 'Environmental Protection Agency', Office of Air and Radiation: 'CLIMATE LEADERS – Greenhouse Gas Inventory Protocol Core Module Guidance, Direct Emissions from Mobile Combustion Sources' (EPA430-K-08-004), available online at www.epa.gov/climateleaders.

NOTE #116: Delivery Leg 5 of 5 from: Joint Air Cargo Facility @ 700 Mexico City Avenue, Kansas City, Kansas, USA (64153-2054); to: Lebanon City Library @ 404 Main Street, Lebanon, Kansas, USA (66952). This involves the further transport of the same package, a distance of 381.0 km (236.7 miles), establishing a 'workload' for this leg of 0.269 metric-tonne kilometres. After factoring for the energy requirements of the 'Light-Duty Truck' we modelled for, the need for 430 kilojoules of energy is established, which is the fuel equivalent of 0.010 kg of diesel oil (assuming an NCV of 42,600 KJ/kg). By applying the '2006 IPCC Guidelines for National Greenhouse Gas Inventories'; but using an even more precise method than the one suggested there; we calculated our 'base carbon dioxide emissions' using a CO₂ intensity factor of 74 mg CO₂ per kilojoule of fuel combusted (at 100% oxidation). We also drew on a select panel of emissions factors to model other emissions, including; carbon monoxide (CO), methane (CH₄), nitrogen oxides (NO+NO₂), nitrous oxide (N₂O), and non-methane volatile organic compounds (NMVOCs). Because the CO, CH₄ and NMVOCs all contain carbon, we then reduced our 'base CO₂ estimate' to bring all of our emissions estimates into 'stoichiometric balance'.

NOTE #117: This truck-borne 'on road' leg for the delivery of the 0.71 kg (1.56 Lb.) hard cover book (corrugated packaging included); with delivery from 'Joint Air Cargo Facility' at 700 Mexico City Avenue in Kansas City, Kansas, USA, -to- 'Lebanon City Library' at 404 Main Street in Lebanon, Kansas, USA; travelled a distance of 381 km (236.7 miles). It was carried on a light-duty truck fuelled with diesel oil and equipped with advanced control emissions abatement technology. The fuel was Diesel Oil of the IEA 2010 North American Default standard, having a 'net calorific value' of 42,600 KJ/kg.

NOTE #118: The combustion of this quantity of this fuel in this truck operating under these conditions, will result in the following airborne emissions; 0.032 kg of carbon dioxide; 0.000062 kg of carbon monoxide; 0.0000008 kg of methane; 0.000047 kg of nitrogen oxides (NO+NO₂); 0.000002 kg of nitrous oxide (N₂O); and 0.000024 kg of non-methane volatile organic compounds (NMVOCs).

NOTE #119: With reliance on research performed by the 'Environmental Protection Agency' in the United States; we can estimate the organic gas constituents that make up the NMVOC emissions, including: 1.73 mg of ethylene; 1.59 mg of toluene; 1.42 mg of isopentane (2-methylbutane); 1.37 mg of acetylene; 1.29 mg of ethylbenzene; 1.07 mg of m & p-xylene; 0.781 mg of benzene; 0.682 mg of n-pentane; 0.607 mg of propylene; 0.440 mg of ethane; 0.423 mg of n-butane; 0.341 mg of o-xylene; 0.213 mg of propane; and 12.2 mg of unidentified (assumed isobutene/1-butene).

NOTE #120: By applying the 'Organic Gas' speciate profile published through the US EPA's "Speciate Data Browser, Version 4.2" (Profile #2563 - 'Roadway - Vehicle Exhaust Emissions - Raleigh' (with the added assumption that the 50.55% unidentified portion, by weight, is actually 'isobutene/1-butene' (CAS 106-98-9), which has an approximately average hydrogen/carbon ratio as seen among the identified speciate constituents in this profile); we were able to perform a 'carbon mass balance' calculation to ensure that no 'double counting' entered our estimates. At their foundations, our estimates are based on the following data points; for carbon dioxide we drew upon IPCC Emission Factor ID #18972 which establishes a rate of emissions of 3172.31 g/kg fuel (Diesel Oil) burned in a Light-Duty Truck; for carbon monoxide we drew upon IPCC Emission Factor ID #18966 which establishes a rate of emissions of 6.11 g/kg fuel (Diesel Oil) burned in a Light-Duty Truck; for methane we drew upon IPCC Emission Factor ID #18960 which establishes a rate of emissions of 0.08 g/kg fuel (Diesel Oil) burned in a Light-Duty Truck; for nitrogen oxides (no+no₂) we drew upon IPCC Emission Factor ID #18957 which establishes a rate of emissions of 4.7 g/kg fuel (Diesel Oil) burned in a Light-Duty Truck; for nitrous oxide we drew upon IPCC Emission Factor ID #18969 which establishes a rate of emissions of 0.23 g/kg fuel (Diesel Oil) burned in a Light-Duty Truck; for non methane volatile organic compounds we drew upon IPCC Emission Factor ID #18963 which establishes a rate of emissions of 2.35 g/kg fuel (Diesel Oil) burned in a Light-Duty Truck. (NB: For factors expressed as a range, we modelled the 'median'.)



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NOTE #121: To calculate fuel requirements, a number of factors were considered. First was the weight of the 0.71 kg (1.56 Lb.) hard cover book (including corrugated packaging), and the fact that it was driven from 'Joint Air Cargo Facility' in Kansas City, to 'Lebanon City Library' in Lebanon, a distance of 381 km (236.7 miles). This establishes a workload of 0.27 metric tonne-kilometres, which when factored against the 1.6 MJ/tonne-km energy intensity factor for trucking published by Michael Landwehr and Céline Marie-Lilliu of the 'International Energy Agency' in 'Transportation Projections in OECD Regions, Detailed Report, May 2002'; Appendix 3, page 155, specific to North America, 2010 fleet (reported as 1.6 MJ/tonne-km of freight); gives us an energy requirement of 430 KJ.

NOTE #122: Because we modelled 'Diesel Oil of the IEA 2010 North American Default' quality as the fuel for this delivery, and because this fuel has a 'net calorific value' of 42,600 KJ/kg, we were able to calculate a fuel requirement of 0.010 kg (0.022 Lbs.). This quantity of fuel, factored against the emissions factors listed below, establishes the CO₂, CO, CH₄, NO+NO₂, N₂O, and NMVOC emissions stemming from this delivery.

NOTE #123: For the sake of comparison; when we multiply this same energy requirement for fuel of 430 KJ, by the fuel-type specific carbon dioxide emissions factor of 0.000074017 kg CO₂/KJ, based on the '2006 IPCC Guidelines for National Greenhouse Gas Inventories', Volume 2, Energy; Chapter 1, Introduction; Table 1.4; Pages 1.23 - 1.24; EXCEPT that the full-fledged scientific calculation was performed, such that 'Diesel Oil', with a default carbon content of 20.2 kg/GJ, when subject to 100% oxidation, and factored for the full molecular weights of CO₂/C (44.00945 / 12.01065), results in 74,017 kg CO₂/TJ (i.e. $20.2 * 1 * (44.00945 / 12.01065) = 74,017$ kg CO₂/TJ). we thus arrive at 0.032 kg CO₂, when we specify the use of diesel oil. This figure is 99.395% of the CO₂ estimate established with reference to the IPCC emissions factor ID#18972. We take this as validation of our model, since this very slight discrepancy can be explained by our use of regional-standard fuels with differing NCVs, rounding errors, and the fact that we use molecular weights in our calculations that are defined out to five decimal places, compared to no decimal places as per the IPCC simplified method.

NOTE #124: With this assurance in our model's calculations, we can turn our attention to rectifying the 'carbon balance' of our calculations. This is necessary because both of the default carbon dioxide emissions factors noted above assume 100% oxidation of the fuel. This means that the other carbonaceous emissions calculated by our analysis, namely carbon monoxide (CO), methane (CH₄), and the non-methane volatile organic compounds (NMVOCs), will effectively count some carbon atoms twice. To avoid this error, we first calculated the CO₂ emissions that would result from the complete combustion of the identified CO and CH₄ emissions, and subtracted these sums from our carbon dioxide estimate. We then did the same thing for each one of the 14 organic gases identified in the US EPA's 'Speciate' (version 4.2) emissions profile (Profile ID# 2563), which together account for 0.077 grams of CO₂, and also subtracted this sum from our CO₂ estimate.

NOTE #125: ALTOGETHER, as noted above; our analysis reveals that the transport of the 0.71 kg (1.56 Lb.) hard cover book (corrugated packaging included); driven from 'Joint Air Cargo Facility' in Kansas City, to 'Lebanon City Library' in Lebanon; on board a 'Light-Duty Truck' fuelled by diesel oil with a 'net calorific value' of 42,600 KJ/kg, RESULTED IN THE FOLLOWING AIRBORNE EMISSIONS: 0.032 kg (0.07 Lb.) of carbon dioxide (CO₂); 0.000062 kg (0.000136 Lb.) of carbon monoxide (CO); 0.000001 kg (0.000002 Lb.) of methane (CH₄); 0.000047 kg (0.000105 Lb.) of nitrogen oxides (NO_x); 0.000002 kg (0.000005 Lb.) of nitrous oxide (N₂O); and 0.000024 kg (0.000052 Lb.) of non-methane organic compounds (NMVOCs).

NOTE #126: Reference Notes RE: IPCC Emission Factor ID #18973 for diesel oil-fuelled light-duty truck freight, emitting carbon dioxide at the rate of 72.098 g/MJ; with applicability as USA / 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-31 on Page 1.74) of the Reference Manual (Estimated Emission Factors for US Light - Duty Diesel Trucks). Data Provider: IPCC. Data provider email: ipcc-efdb@iges.or.jp *AND* RE: IPCC Emission Factor ID #18972 for diesel oil-fuelled Light-Duty Truck freight, emitting carbon dioxide at the rate of 3172.31 g/kg fuel (equivalent to 3172.31 g/kg fuel); with application as US / 1996 IPCC Global Default. Data reported to EFDB: carbon dioxide emissions of 3172.31 g/kg fuel. Data source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-31 on Page 1.74) of the Reference Manual (Estimated Emission Factors for US Light - Duty Diesel Trucks).

NOTE #127: Reference Notes RE: IPCC Emission Factor ID #18967 for diesel oil-fuelled light-duty truck freight, emitting carbon monoxide at the rate of 0.139 g/MJ; with applicability as USA / 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-31 on Page 1.74) of the Reference Manual (Estimated Emission Factors for US Light - Duty Diesel Trucks). Data Provider: IPCC. Data provider email: ipcc-efdb@iges.or.jp *AND* RE: IPCC Emission Factor ID #18966 for diesel oil-fuelled Light-Duty Truck freight, emitting carbon monoxide at the rate of 6.11 g/kg fuel (equivalent to 6.11 g/kg fuel); with application as US / 1996 IPCC Global Default. Data reported to EFDB: carbon monoxide emissions of 6.11 g/kg fuel. Data source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-31 on Page 1.74) of the Reference Manual (Estimated Emission Factors for US Light - Duty Diesel Trucks).



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NOTE #128: Reference Notes RE: IPCC Emission Factor ID #18961 for diesel oil-fuelled light-duty truck freight, emitting methane at the rate of 0.002 g/MJ; with applicability as USA / 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-31 on Page 1.74) of the Reference Manual (Estimated Emission Factors for US Light - Duty Diesel Trucks). Data Provider: IPCC. Data provider email: ipcc-efdb@iges.or.jp *AND* RE: IPCC Emission Factor ID #18960 for diesel oil-fuelled Light-Duty Truck freight, emitting methane at the rate of 0.08 g/kg fuel (equivalent to 0.08 g/kg fuel); with application as US / 1996 IPCC Global Default. Data reported to EFDB: methane emissions of 0.08 g/kg fuel. Data source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-31 on Page 1.74) of the Reference Manual (Estimated Emission Factors for US Light - Duty Diesel Trucks).

NOTE #129: Reference Notes RE: IPCC Emission Factor ID #18958 for diesel oil-fuelled light-duty truck freight, emitting nitrogen oxides (NO+NO₂) at the rate of 0.107 g/MJ; with applicability as USA / 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-31 on Page 1.74) of the Reference Manual (Estimated Emission Factors for US Light - Duty Diesel Trucks). Data Provider: IPCC. Data provider email: ipcc-efdb@iges.or.jp *AND* RE: IPCC Emission Factor ID #18957 for diesel oil-fuelled Light-Duty Truck freight, emitting nitrogen oxides (NO+NO₂) at the rate of 4.7 g/kg fuel (equivalent to 4.7 g/kg fuel); with application as US / 1996 IPCC Global Default. Data reported to EFDB: nitrogen oxides (NO+NO₂) emissions of 4.7 g/kg fuel. Data source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-31 on Page 1.74) of the Reference Manual (Estimated Emission Factors for US Light - Duty Diesel Trucks).

NOTE #130: Reference Notes RE: IPCC Emission Factor ID #18970 for diesel oil-fuelled light-duty truck freight, emitting nitrous oxide at the rate of 0.005 g/MJ; with applicability as USA / 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-31 on Page 1.74) of the Reference Manual (Estimated Emission Factors for US Light - Duty Diesel Trucks). Data Provider: IPCC. Data provider email: ipcc-efdb@iges.or.jp *AND* RE: IPCC Emission Factor ID #18969 for diesel oil-fuelled Light-Duty Truck freight, emitting nitrous oxide at the rate of 0.23 g/kg fuel (equivalent to 0.23 g/kg fuel); with application as US / 1996 IPCC Global Default. Data reported to EFDB: NITROUS OXIDE emissions of 0.23 g/kg fuel. Data source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-31 on Page 1.74) of the Reference Manual (Estimated Emission Factors for US Light - Duty Diesel Trucks).

NOTE #131: Reference Notes RE: IPCC Emission Factor ID #18964 for diesel oil-fuelled light-duty truck freight, emitting non methane volatile organic compounds at the rate of 0.053 g/MJ; with applicability as USA / 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-31 on Page 1.74) of the Reference Manual (Estimated Emission Factors for US Light - Duty Diesel Trucks). Data Provider: IPCC. Data provider email: ipcc-efdb@iges.or.jp *AND* RE: IPCC Emission Factor ID #18963 for diesel oil-fuelled Light-Duty Truck freight, emitting non methane volatile organic compounds at the rate of 2.35 g/kg fuel (equivalent to 2.35 g/kg fuel); with application as US / 1996 IPCC Global Default. Data reported to EFDB: NON methane VOLATILE ORGANIC COMPOUNDS emissions of 2.35 g/kg fuel. Data source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-31 on Page 1.74) of the Reference Manual (Estimated Emission Factors for US Light - Duty Diesel Trucks).

NOTE #132: ALL-ROAD delivery from: Fictitious Print Plant @ 11 Havenbrook Blvd., Toronto, Ontario, Canada (M2J 1A5); to: Lebanon City Library @ 404 Main Street, Lebanon, Kansas, USA (66952). The 'all-road' delivery scenario we modelled also involves the transport of a 0.71 kg (1.56 Lb.) package; HOWEVER, for a total distance of 1,916 km (1,191 miles), establishing a 'workload' for this end-to-end delivery of 1.35 metric-tonne kilometres. After factoring for the energy requirements of the 'Heavy-Duty Truck' we modelled for, the need for 2,163 kilojoules of energy is established, which is the fuel equivalent of 0.051 kg of diesel oil (assuming an NCV of 42,600 KJ/kg). By applying the '2006 IPCC Guidelines for National Greenhouse Gas Inventories'; but using an even more precise method than the one suggested there; we calculated our 'base carbon dioxide emissions' using a CO₂ intensity factor of 74 mg CO₂ per kilojoule of fuel combusted (at 100% oxidation). We also drew on a select panel of emissions factors to model other emissions, including; carbon monoxide (CO), methane (CH₄), nitrogen oxides (NO+NO₂), nitrous oxide (N₂O), and non-methane volatile organic compounds (NMVOCs). Because the CO, CH₄ and NMVOCs all contain carbon, we then reduced our 'base CO₂ estimate' to bring all of our emissions estimates into 'stoichiometric balance'.

NOTE #133: This truck-borne 'on road' leg for the delivery of the 0.71 kg (1.56 Lb.) hard cover book (corrugated packaging included); with delivery from 'Fictitious Printing Plant' at 11 Havenbrook Boulevard in Toronto, Ontario, Canada, -to- 'Vista Cargo Centre - Pearson International Airport' at 6500 Silver Dart Drive in Mississauga, Ontario, Canada; travelled a distance of 26.9 km (16.7 miles). It was carried on a heavy-duty truck fuelled with diesel oil and equipped with advanced control emissions abatement technology. The fuel was Diesel Oil of the IEA 2010 North American Default standard, having a 'net calorific value' of 42,600 KJ/kg.

NOTE #134: The combustion of this quantity of this fuel in this truck operating under these conditions, will result in the following airborne emissions; 0.0022 kg of carbon dioxide; 0.000010 kg of carbon monoxide; 0.0000001 kg of methane; 0.000008 kg of



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nitrogen oxides (NO+NO₂); 0.000000 kg of nitrous oxide (N₂O); and 0.000002 kg of non-methane volatile organic compounds (NMVOCs).

NOTE #135: With reliance on research performed by the 'Environmental Protection Agency' in the United States; we can estimate the organic gas constituents that make up the NMVOC emissions, including: 0.144 mg of ethylene; 0.133 mg of toluene; 0.119 mg of isopentane (2-methylbutane); 0.114 mg of acetylene; 0.107 mg of ethylbenzene; 0.0894 mg of m & p-xylene; 0.0652 mg of benzene; 0.0569 mg of n-pentane; 0.0507 mg of propylene; 0.0367 mg of ethane; 0.0353 mg of n-butane; 0.0285 mg of o-xylene; 0.0178 mg of propane; and 1.02 mg of unidentified (assumed isobutene/1-butene).

NOTE #136: By applying the 'Organic Gas' speciate profile published through the US EPA's "Speciate Data Browser, Version 4.2" (Profile #2563 - 'Roadway - Vehicle Exhaust Emissions - Raleigh' (with the added assumption that the 50.55% unidentified portion, by weight, is actually 'isobutene/1-butene' (CAS 106-98-9), which has an approximately average hydrogen/carbon ratio as seen among the identified speciate constituents in this profile); we were able to perform a 'carbon mass balance' calculation to ensure that no 'double counting' entered our estimates. At their foundations, our estimates are based on the following data points; for carbon dioxide we drew upon IPCC Emission Factor ID #19026 which establishes a rate of emissions of 3172.31 g/kg fuel (Diesel Oil) burned in a Heavy-Duty Truck; for carbon monoxide we drew upon IPCC Emission Factor ID #19020 which establishes a rate of emissions of 14.01 g/kg fuel (Diesel Oil) burned in a Heavy-Duty Truck; for methane we drew upon IPCC Emission Factor ID #19014 which establishes a rate of emissions of 0.14 g/kg fuel (Diesel Oil) burned in a Heavy-Duty Truck; for nitrogen oxides (no+no₂) we drew upon IPCC Emission Factor ID #19011 which establishes a rate of emissions of 11.32 g/kg fuel (Diesel Oil) burned in a Heavy-Duty Truck; for nitrous oxide we drew upon IPCC Emission Factor ID #19023 which establishes a rate of emissions of 0.08 g/kg fuel (Diesel Oil) burned in a Heavy-Duty Truck; for non methane volatile organic compounds we drew upon IPCC Emission Factor ID #19017 which establishes a rate of emissions of 2.78 g/kg fuel (Diesel Oil) burned in a Heavy-Duty Truck. (NB: For factors expressed as a range, we modelled the 'median'.)

NOTE #137: To calculate fuel requirements, a number of factors were considered. First was the weight of the 0.71 kg (1.56 Lb.) hard cover book (including corrugated packaging), and the fact that it was driven from 'Fictitious Printing Plant' in Toronto, to 'Vista Cargo Centre - Pearson International Airport' in Mississauga, a distance of 26.9 km (16.7 miles). This establishes a workload of 0.019 metric tonne-kilometres, which when factored against the 1.6 MJ/tonne-km energy intensity factor for trucking published by Michael Landwehr and Céline Marie-Lilliu of the 'International Energy Agency' in 'Transportation Projections in OECD Regions, Detailed Report, May 2002'; Appendix 3, page 155, specific to North America, 2010 fleet (reported as 1.6 MJ/tonne-km of freight); gives us an energy requirement of 30 KJ.

NOTE #138: Because we modelled 'Diesel Oil of the IEA 2010 North American Default' quality as the fuel for this delivery, and because this fuel has a 'net calorific value' of 42,600 KJ/kg, we were able to calculate a fuel requirement of 0.001 kg (0.002 Lbs.). This quantity of fuel, factored against the emissions factors listed below, establishes the CO₂, CO, CH₄, NO+NO₂, N₂O, and NMVOC emissions stemming from this delivery.

NOTE #139: For the sake of comparison; when we multiply this same energy requirement for fuel of 30 KJ, by the fuel-type specific carbon dioxide emissions factor of 0.000074017 kg CO₂/KJ, based on the '2006 IPCC Guidelines for National Greenhouse Gas Inventories', Volume 2, Energy; Chapter 1, Introduction; Table 1.4; Pages 1.23 - 1.24; EXCEPT that the full-fledged scientific calculation was performed, such that 'Diesel Oil', with a default carbon content of 20.2 kg/GJ, when subject to 100% oxidation, and factored for the full molecular weights of CO₂/C (44.00945 / 12.01065), results in 74,017 kg CO₂/TJ (i.e. 20.2 * 1 * (44.00945 / 12.01065) = 74,017 kg CO₂/TJ). we thus arrive at 0.002 kg CO₂, when we specify the use of diesel oil. This figure is 99.395% of the CO₂ estimate established with reference to the IPCC emissions factor ID#19026. We take this as validation of our model, since this very slight discrepancy can be explained by our use of regional-standard fuels with differing NCVs, rounding errors, and the fact that we use molecular weights in our calculations that are defined out to five decimal places, compared to no decimal places as per the IPCC simplified method.

NOTE #140: With this assurance in our model's calculations, we can turn our attention to rectifying the 'carbon balance' of our calculations. This is necessary because both of the default carbon dioxide emissions factors noted above assume 100% oxidation of the fuel. This means that the other carbonaceous emissions calculated by our analysis, namely carbon monoxide (CO), methane (CH₄), and the non-methane volatile organic compounds (NMVOCs), will effectively count some carbon atoms twice. To avoid this error, we first calculated the CO₂ emissions that would result from the complete combustion of the identified CO and CH₄ emissions, and subtracted these sums from our carbon dioxide estimate. We then did the same thing for each one of the 14 organic gases identified in the US EPA's 'Speciate' (version 4.2) emissions profile (Profile ID# 2563), which together account for 0.006 grams of CO₂, and also subtracted this sum from our CO₂ estimate.



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NOTE #141: ALTOGETHER, as noted above; our analysis reveals that the transport of the 0.71 kg (1.56 Lb.) hard cover book (corrugated packaging included); driven from 'Fictitious Printing Plant' in Toronto, to 'Vista Cargo Centre - Pearson International Airport' in Mississauga; on board a 'Heavy-Duty Truck' fuelled by diesel oil with a 'net calorific value' of 42,600 KJ/kg, RESULTED IN THE FOLLOWING AIRBORNE EMISSIONS: 0.0022 kg (0.0049 Lb.) of carbon dioxide (CO₂); 0.00001 kg (0.000022 Lb.) of carbon monoxide (CO); 0 kg (0 Lb.) of methane (CH₄); 0.000008 kg (0.000018 Lb.) of nitrogen oxides (NO_x); 0 kg (0 Lb.) of nitrous oxide (N₂O); and 0.000002 kg (0.000004 Lb.) of non-methane organic compounds (NMVOCs).

NOTE #142: Reference Notes RE: IPCC Emission Factor ID #19027 for diesel oil-fuelled heavy-duty truck freight, emitting carbon dioxide at the rate of 72.098 g/MJ; with applicability as USA / 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles). Data Provider: IPCC. Data provider email: ipcc-efdb@iges.or.jp *AND* RE: IPCC Emission Factor ID #19026 for diesel oil-fuelled heavy-duty truck freight, emitting carbon dioxide at the rate of 3172.31 g/kg fuel (equivalent to 3172.31 g/kg fuel); with application as US / 1996 IPCC Global Default. Data reported to EFDB: carbon dioxide emissions of 3172.31 g/kg fuel. Data source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles).

NOTE #143: Reference Notes RE: IPCC Emission Factor ID #19021 for diesel oil-fuelled heavy-duty truck freight, emitting carbon monoxide at the rate of 0.318 g/MJ; with applicability as USA / 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles). Data Provider: IPCC. Data provider email: ipcc-efdb@iges.or.jp *AND* RE: IPCC Emission Factor ID #19020 for diesel oil-fuelled heavy-duty truck freight, emitting carbon monoxide at the rate of 14.01 g/kg fuel (equivalent to 14.01 g/kg fuel); with application as US / 1996 IPCC Global Default. Data reported to EFDB: carbon monoxide emissions of 14.01 g/kg fuel. Data source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles).

NOTE #144: Reference Notes RE: IPCC Emission Factor ID #19015 for diesel oil-fuelled heavy-duty truck freight, emitting methane at the rate of 0.003 g/MJ; with applicability as USA / 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles). Data Provider: IPCC. Data provider email: ipcc-efdb@iges.or.jp *AND* RE: IPCC Emission Factor ID #19014 for diesel oil-fuelled heavy-duty truck freight, emitting methane at the rate of 0.14 g/kg fuel (equivalent to 0.14 g/kg fuel); with application as US / 1996 IPCC Global Default. Data reported to EFDB: methane emissions of 0.14 g/kg fuel. Data source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles).

NOTE #145: Reference Notes RE: IPCC Emission Factor ID #19012 for diesel oil-fuelled heavy-duty truck freight, emitting nitrogen oxides (NO+NO₂) at the rate of 0.257 g/MJ; with applicability as USA / 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles). Data Provider: IPCC. Data provider email: ipcc-efdb@iges.or.jp *AND* RE: IPCC Emission Factor ID #19011 for diesel oil-fuelled heavy-duty truck freight, emitting nitrogen oxides (NO+NO₂) at the rate of 11.32 g/kg fuel (equivalent to 11.32 g/kg fuel); with application as US / 1996 IPCC Global Default. Data reported to EFDB: nitrogen oxides (NO+NO₂) emissions of 11.32 g/kg fuel. Data source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles).

NOTE #146: Reference Notes RE: IPCC Emission Factor ID #19024 for diesel oil-fuelled heavy-duty truck freight, emitting nitrous oxide at the rate of 0.002 g/MJ; with applicability as USA / 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles). Data Provider: IPCC. Data provider email: ipcc-efdb@iges.or.jp *AND* RE: IPCC Emission Factor ID #19023 for diesel oil-fuelled heavy-duty truck freight, emitting nitrous oxide at the rate of 0.08 g/kg fuel (equivalent to 0.08 g/kg fuel); with application as US / 1996 IPCC Global Default. Data reported to EFDB: NITROUS OXIDE emissions of 0.08 g/kg fuel. Data source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles).

NOTE #147: Reference Notes RE: IPCC Emission Factor ID #19018 for diesel oil-fuelled heavy-duty truck freight, emitting non methane volatile organic compounds at the rate of 0.063 g/MJ; with applicability as USA / 1996 IPCC global default. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles). Data Provider: IPCC. Data provider email: ipcc-efdb@iges.or.jp *AND* RE: IPCC Emission Factor ID #19017 for diesel oil-fuelled heavy-duty truck freight, emitting non methane volatile organic compounds at



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the rate of 2.78 g/kg fuel (equivalent to 2.78 g/kg fuel); with application as US / 1996 IPCC Global Default. Data reported to EFDB: NON methane VOLATILE ORGANIC COMPOUNDS emissions of 2.78 g/kg fuel. Data source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Table 1-32 on Page 1.75) of the Reference Manual (Estimated Emission Factors for US Heavy Duty Diesel Vehicles).