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RSB Fossil Fuel Baseline Calculation Methodology

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Contact details: RSB - Roundtable on Sustainable Biofuels
EPFL - Ecole Polytechnique Federale De Lausanne
Energy Center
Château de Bassenges, Station 5
CH - 1015 Lausanne
Switzerland
web: http://rsb.epfl.ch
email: rsb@epfl.ch

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Introduction

The Roundtable on Sustainable Biofuels (RSB) Standard has a requirement for minimum greenhouse gas (GHG) emission reductions with respect to the applicable fossil fuel baseline for biofuels replacing gasoline, diesel and jet kerosene. The RSB has developed an RSB GHG Calculation Methodology for the lifecycle GHG emissions of biofuels (RSB-STD-01-003-01). In this document, we present the RSB Fossil Fuel Baseline (RSB-STD-01-003-02).

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A. Intent of this Standard

This standard is intended to encompass the calculation of the fossil fuel baseline for gasoline, diesel, and jet kerosene. The fossil fuel baseline contained herein is to be used by *participating operator*s in the *RSB certification scheme* when demonstrating compliance with Principle 3, Greenhouse Gas Emissions.

The intent of this standard is to ensure that all operators participating in the *RSB certification systems* use the same values for the fossil fuel baseline that is referred to in Principle 3.

B. Scope of this Standard

This standard is an international standard and valid worldwide, and specifies the fossil fuel baseline values to be used by RSB *participating operators*.

C. Status and Effective Date of this Standard

The version 2.0 of the RSB Fossil Fuel Baseline shall be effective on 1 March 2011.

D. Note on the Use of this Standard

All aspects of this standard are considered to be normative, including the intent, scope, standard effective date, note on the use of this standard, references, terms and definitions, requirements and annexes, unless otherwise stated. Users implementing this standard shall ensure that the intent of this standard is met. To ensure that the intent of this standard is met users shall implement all of the requirements specified in this standard, and any and all additional measures necessary to achieve the intent of this standard.

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1. Executive Summary

The RSB Fossil Fuel Baseline was developed according to the decision of the RSB Steering Board in its in-person November 2010 meeting: the fossil fuel baseline must be a global average value, determined for gasoline, diesel and jet kerosene, and it must be re-evaluated periodically if there are changes in fossil fuel production and use that warrant such revisions. *The frequency of periodic re-evaluation has not been determined at this point and will be discussed by the Steering Board in an upcoming in-person meeting*.

In conducting this work, the RSB Secretariat received guidance from Jean François Larive, an oil & gas industry expert with experience in LCA of fossil fuels and biofuels. In addition, this work was peer reviewed by various experts and stakeholders; the results of the peer review are published in Annex 2.

It must be noted that the fossil fuel baseline (and associated uncertainty) presented herein constitutes an estimate. However, the RSB deems that the values presented herein are accurate enough to be used for the purpose of compliance with Principle 3.

The estimation of the GHG intensity values was broken down into the lifecycle stages of fossil fuels, namely crude oil production, fuel production, transportation & storage, and use. The results obtained and the main assumptions made are shown in Table 1. Based on the data presented in that table, the fossil fuel baseline, to be used to demonstrate compliance with Criterion 3c of the RSB Standard, is as follows:

- Gasoline : 90 gCO2e/MJ;
- Diesel: 90 gCO2e/MJ;
- Kerosene-based Jet: 90 gCO2e/MJ.

In the values presented above, we have rounded to no decimals given the uncertainty estimated. The uncertainty estimated amounts roughly ± 3 gCO2e/MJ.

Crude oil production GHG intensity data were derived mainly from (NETL, 2008), who did the fossil fuel baseline calculation for the U.S. RFS2. These values are based on 2008 crude oil production profiles. Unconventional fossil fuel production is specifically addressed in the Canadian profile (of relevance to the U.S.) but not specifically addressed for other countries; going forward, it is important to assess the changes in the types of crude oil produced globally, to determine whether there is an increasing proportion of such fuels from unconventional sources, and to determine whether this has a significant impact on the above values.

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Table 1: GHG intensity of fossil fuels estimated in this study and main assumptions (gCO2e/MJ)

Lifecycle stage	*Estimated emissions (gCO2e/MJ)*			*Main assumptions*
	Gasoline	*Diesel*	*Jet Kerosene*	
Crude oil production	5.6	5.6	5.6	BP Statistics global crude oil production data (BP, 2010); (NETL, 2008)GHG intensity of crude oil production by country
Crude oil transport	1.3	1.3	1.3	Assumed standard distances and transport modes for each barrel of fuel
Fuel production	9.4	9.4	9.4	Based on (NETL, 2008) refinery GHG emissions; allocation was done differently from (NETL, 2008) and was based on economic value of refinery products
Finished fuel transport	0.6	0.6	0.6	Assumed standard distances and transport modes for each barrel of fuel
Use	73.3	73.2	73.2	Stoichiometric CO2 emissions assuming full combustion of carbon in fuel following (JEC, 2007)
Total	90.1	90.0	90.0	--
Rounded	90	90	90	--

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2. Background, Aim and Scope of this work

The aim of the work described in this document is to estimate the lifecycle GHG emissions of fossil fuels as a global average, taking into account the steps of crude oil production, refining, and transportation and distribution. This work is only meant to address direct impacts of fossil fuel production on GHG emissions.

Given the limited time and financial resources available to the RSB, the work conducted does not constitute an in-depth research exercise; rather, the results presented here build on existing data published by other institutions.

3. Calculation of Lifecycle Fossil Fuel Baseline

3.1.Crude oil production

Global crude oil production data for the year 2009 for 49 countries and 5 regions were taken from (BP, 2010). These data are shown in Table 2.

Table 2 also shows the GHG intensity of crude oil production in these countries: the GHG intensity number for each country was either taken directly from (NETL, 2008) or derived from the numbers published in that study.

For those countries for which there were no published GHG intensity values in (NETL, 2008), values were derived by calculating a regional average from other countries with published data. For example, the value for the United Arab Emirates was derived by taking the average of Saudi Arabia and Iraq. This is shown in Table 2.

(NETL, 2008) conducted a calculation of the carbon intensity of U.S. fossil fuels. These values include GHG emissions from oil exploration and production, including flaring & venting (F&V). For 10 countries, (NETL, 2008) obtained country-specific crude oil extraction profiles from PE International (2008); such profiles are in (NETL, 2008). For another 16 countries, (NETL, 2009) obtained country-specific in-country delivered crude oil mix profiles from GaBi 4 Life Cycle Assessment Software, Professional Database (2007); these profiles are shown in Figure 2.5 of (NETL, 2008) and were read off the figure with the highest possible accuracy in order to be able to use them in this study. (NETL, 2008) derived the Canada profile individually for conventional oil and tar sands.

In this study, 55% of Canadian crude oil production was assumed to come from tar sands. This value was cited in (CAPP, 2010).

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A global average GHG intensity value for crude oil production was then calculated by weighting country GHG values according to the crude oil production in each country, for the top world producing countries.

The world average crude oil production GHG intensity was thus estimated based as 5.6 ± 30% gCO2e/MJ of crude oil produced. This value was applied to the production of gasoline, diesel, and kerosene-based jet. Hence, emissions associated with crude oil production are:

- Gasoline: 5.6 ± 30% gCO2e/MJ-fuel;
- Diesel: 5.6 ± 30% gCO2e/MJ-fuel;
- Kerosene and Kerosene-based Jet: 5.6 ± 30% gCO2e/MJ-fuel.

Table 2: Crude oil production for top producing countries / regions in 2009 (BP, 2010) and associated GHG emissions

This table shows oil production in the top 49 producing countries and oil production in "other" countries in five regions; the data are from (BP, 2010). In addition, this table shows GHG emissions associated with crude oil production in each country/region. The source of the data and assumptions made is shown for each country and region.

Million tonnes	2009, million tons	% of World total	kg CO2e/ toe	gCO2e / MJ*	Weighted gCO2e/ MJ	Source
Russian Federation	**494.2**	**12.94%**	237.25	5.67	0.73	NETL 2008, GaBi 4
Saudi Arabia	**459.5**	**12.03%**	99.28	2.37	0.29	NETL 2008, PE Intl (2008)
US	**325.3**	**8.52%**	178.85	4.27	0.36	NETL 2008, PE Intl (2008)
Iran	**202.4**	**5.30%**	121.18	2.89	0.15	Average (Iraq; Saudi Arabia)
China	**189.0**	**4.95%**	301.49	7.20	0.36	NETL 2008, GaBi 4
Canada	**155.7**	**4.08%**	561.37	13.41	0.55	NETL 2008; assumed tar sands fraction
Mexico	**147.5**	**3.86%**	280.32	6.70	0.26	NETL 2008, PE Intl (2008)
Venezuela	**124.8**	**3.27%**	176.66	4.22	0.14	NETL 2008, PE Intl (2008)
Iraq	**121.8**	**3.19%**	143.08	3.42	0.11	NETL 2008, PE Intl (2008)
Kuwait	**121.3**	**3.18%**	120.45	2.88	0.09	NETL 2008, PE Intl (2008)
United Arab Emirates	**120.6**	**3.16%**	121.18	2.89	0.09	Average (Iraq; Saudi Arabia)
Norway	**108.3**	**2.84%**	40.88	0.98	0.03	NETL 2008, GaBi 4
Brazil	**100.4**	**2.63%**	259.88	6.21	0.16	NETL 2008, GaBi 4
Nigeria	**99.1**	**2.60%**	938.78	22.42	0.58	NETL 2008, PE Intl (2008)
Angola	**87.4**	**2.29%**	597.14	14.26	0.33	NETL 2008, PE Intl (2008)
Kazakhstan	**78.0**	**2.04%**	237.25	5.67	0.12	Used same as Russia
Algeria	**77.6**	**2.03%**	256.23	6.12	0.12	NETL 2008, PE Intl (2008)
Libya	**77.1**	**2.02%**	121.18	2.89	0.06	Average (Iraq; Saudi Arabia)
United Kingdom	**68.0**	**1.78%**	100.74	2.41	0.04	NETL 2008, GaBi 4
Qatar	**57.9**	**1.51%**	121.18	2.89	0.04	Average (Iraq; Saudi Arabia)
Azerbaijan	**50.6**	**1.33%**	121.18	2.89	0.04	Average (Iraq; Saudi Arabia)
Indonesia	**49.0**	**1.28%**	255.87	6.11	0.08	Average (China; Australia)
Oman	**38.5**	**1.01%**	121.18	2.89	0.03	Average (Iraq; Saudi Arabia)
India	**35.4**	**0.93%**	255.87	6.11	0.06	Average (China; Australia)
Egypt	**35.3**	**0.92%**	121.18	2.89	0.03	Average (Iraq; Saudi Arabia)

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Million tonnes	2009, million tons	% of World total	kg CO2e/ toe	gCO2e / MJ*	Weighted gCO2e/ MJ	Source
Colombia	**34.1**	**0.89%**	221.68	5.29	0.05	Average (Venezuela; Brazil; Ecuador)
Argentina	**33.8**	**0.88%**	221.68	5.29	0.05	Average (Venezuela; Brazil; Ecuador)
Malaysia	**33.2**	**0.87%**	255.87	6.11	0.05	Average (China; Australia)
Ecuador	**25.2**	**0.66%**	228.49	5.46	0.04	NETL 2008, PE Intl (2008)
Sudan	**24.1**	**0.63%**	597.38	14.27	0.09	Average(Nigeria; Angola; Algeria)
Australia	**23.6**	**0.62%**	210.24	5.02	0.03	NETL 2008, GaBi 4
Other Europe & Eurasia	**19.0**	**0.50%**	182.50	4.36	0.02	NETL 2008, EU-25 value
Syria	**18.7**	**0.49%**	121.18	2.89	0.01	Average (Iraq; Saudi Arabia)
Vietnam	**16.8**	**0.44%**	255.87	6.11	0.03	Average (China; Australia)
Equatorial Guinea	**15.2**	**0.40%**	597.38	14.27	0.06	Average(Nigeria; Angola; Algeria)
Other Asia Pacific	**14.2**	**0.37%**	255.87	6.11	0.02	Average (China; Australia)
Rep. of Congo (Brazzaville)	**14.1**	**0.37%**	597.38	14.27	0.05	Average(Nigeria; Angola; Algeria)
Yemen	**14.0**	**0.37%**	121.18	2.89	0.01	Average (Iraq; Saudi Arabia)
Thailand	**13.6**	**0.36%**	255.87	6.11	0.02	Average (China; Australia)
Denmark	**12.9**	**0.34%**	182.50	4.36	0.01	NETL 2008, EU-25 value
Gabon	**11.4**	**0.30%**	597.38	14.27	0.04	Average(Nigeria; Angola; Algeria)
Turkmenistan	**10.2**	**0.27%**	237.25	5.67	0.02	Used same as Russia
Brunei	**8.2**	**0.21%**	255.87	6.11	0.01	Average (China; Australia)
Other S. & Cent. America	**7.1**	**0.19%**	221.68	5.29	0.01	Average (Venezuela; Brazil; Ecuador)
Trinidad & Tobago	**6.8**	**0.18%**	221.68	5.29	0.01	Average (Venezuela; Brazil; Ecuador)
Peru	**6.4**	**0.17%**	221.68	5.29	0.01	Average (Venezuela; Brazil; Ecuador)
Chad	**6.2**	**0.16%**	597.38	14.27	0.02	Average(Nigeria; Angola; Algeria)
Italy	**4.6**	**0.12%**	182.50	4.36	0.01	NETL 2008, EU-25 value
Uzbekistan	**4.5**	**0.12%**	237.25	5.67	0.01	Used same as Russia
Romania	**4.5**	**0.12%**	182.50	4.36	0.01	NETL 2008, EU-25 value
Tunisia	**4.1**	**0.11%**	597.38	14.27	0.02	Average(Nigeria; Angola; Algeria)
Other Africa	**3.9**	**0.10%**	597.38	14.27	0.01	Average(Nigeria; Angola; Algeria)
Cameroon	**3.7**	**0.10%**	597.38	14.27	0.01	Average(Nigeria; Angola; Algeria)
Other Middle East	**1.7**	**0.04%**	121.18	2.89	0.00	Average (Iraq; Saudi Arabia)
World Total	**3820.5**	**100.00%**	--	--	**5.57**	

*Conversion used: 1 toe = 41.87 GJ

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3.1.1. Data quality review & discussion

(Larive, 2011) conducted a calculation of EU fossil fuels and determined the GHG emissions of crude oil production for the crude oil used in the EU.

One of the sources utilized in deriving these data is the International Association of Oil & Gas Producers, which has collected data on energy and GHG emissions associated with crude oil production from its members for a number of years; the data for 2005 are shown in the (Larive, 2011) report and are cited here as (OGP, 2005). The OGP coverage is very good for Europe, fair for Africa and South America but rather patchy for other regions, particularly the Former Soviet Union. From (Larive, 2011), "The OGP report indicates that about 50% of the GHG emissions that have been attributed are related to F&V. However, 35% of the reported emissions have not been specified. If one assumes that these are not related to F&V, this would reduce the proportion of F&V emissions to about 33% of the total. In other words the OGP data point out to emissions of **2.0 to 2.6 g CO_2/MJ crude for production operations** and 1.3 to 2 g CO_2/MJ crude for F&V." This results in a range of 3.3 to 4.6 g CO_2/MJ according to (Larive, 2011). Hence, the GHG intenstiy of crude oil production in (OGP, 2005) is generally lower than in (NETL, 2008).

JEC recognized that the OGP data may underestimate the F&V emissions because it is limited to OGP members which are not fully representative of the total and also who tend to be dominated by International Oil Companies who may have lower GHG intensity potentially due to stricter requirements around flaring reduction than national oil companies (NOCs).

(Larive, 2011) therefore used F&V emissions information from the National Oceanic and Atmospheric Administration data published on the basis of satellite observations (NOAA, 2010). Based on these data, (Larive, 2011) adopted a figure of **2.5 g/MJ with an uncertainty range of ±50%** for F&V (1.3-2.8)

When using the higher F&V values from NOAA in conjunction with the oil production values from (OGP, 2005) (excluding F&V), the JEC world average best estimate increases to 4.8 gCO_{2e}/MJ with a range of 3.3 to 5.4 i.e. closer to those published in (NETL, 2008), for which no uncertainty range is indicated.

Kloverpris et al. (see Annex 2) extracted flaring data from (NOAA, 2010) and calculated venting data based on flaring to venting ratios published in the PE International profiles of (NETL, 2008). The F&V emissions calculated are, on average, the same magnitude as the total GHG emissions associated with crude oil production determined in this study (Table 2). One of the reasons for the higher F&V data in Kloverpris et al. is the fact that the flaring data from NOAA are for crude oil *and* natural gas production; we believe that the flaring and venting emissions cited in the PE International profiles of (NETL, 2008) also apply to crude oil plus natural gas production, but we could not verify this with the authors of the PE International data. It was not possible to ascertain the uncertainty associated with the PE International data. It must be considered that the flaring to venting ratios in (NETL, 2008) are published in the same source that was used as

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the main reference for GHG intensities of crude oil production. Hence this begs the question of how the PE International profile data were used by EPA to conduct the calculations in (NETL, 2008).

Note that (Larive, 2011) adjusted flaring and venting data published by NOAA; (Larive, 2011) apportioned emissions between all hydrocarbons produced by assuming "that F&V emissions are distributed in proportion of the energy content of all hydrocarbons produced. This reduces the specific F&V emissions from 3.2 to 2 g/MJ of hydrocarbon produced".

However, even assuming that 50% of the F&V emissions calculated by Kloverpris et al. are attributable to natural gas production, their estimates of F&V are still higher than those in (Larive, 2011). Overall it can be seen that there is a high degree of uncertainty surrounding GHG intensity data for crude oil production, and especially for emissions from F&V.

The **California Low Carbon Fuel Standard (LCFS)** has estimated lifecycle GHG emissions for fossil fuels (gasoline and diesel). For the production of crude oils relevant to California (crude oil recovery), the value is 6.93 gCO2e/MJ (, which is within the uncertainty range estimated in this work. The value was derived using the GREET model adapted to California; it includes an assessment of the different crude oil sources for California refineries, and associated extraction efficiencies. The work is described in (LCFS, Detailed California-Modified GREET Pathway for Ultra Low Sulfur Diesel (ULSD) from Average Crude Refined in California, February 28, 2009, 2009a) and (LCFS, 2009b).

3.1.2. Estimated Uncertainty

(NETL, 2009) does not include an uncertainty assessment. The range estimated by (JEC, 2011) is ±30%. This uncertainty range is not the same as the range of emissions pertaining to specific crude oils, which is considerably broader.

3.1.3. Best Estimate

In conclusion, figures in (NETL, 2008) *are somewhat higher than in (JEC, 2011) but both figures are still mutually compatible in view of the high degree of uncertainty attached to such estimates. The F&V calculations of F&V emissions conducted by Kloverpris et al. have considerably higher values than those used in this study, but given the uncertainties associated with that calcualtion (and the PE International profile data), we did not use those data.*

Our best estimate is 5.6 ±30% or a range of 4.9 to 7.3 g CO_{2e}/MJ crude oil.

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3.2.Refining

(NETL, 2008) propose a volumetric allocation methodology based on U.S. petroleum refining operations in 2005. Refining emissions are broken down into:

- Acquisition of fuels used in refining operations;
- Combustion of fuels at the refinery;
- Hydrogen production;
- Flaring, venting and fugitive emissions.

The emissions from the refinery operations are allocated to the various products resulting from refinery operations, including gasoline, diesel fuel, kerosene-based jet fuel, light ends, residual fuel oil, heavy ends, and coke. The deemed consumption of resources (hydrocarbon feedstocks, fuels/energy, and hydrogen) of each main process unit is allocated between its products which are in turn allocated to one of the final product basket (such as gasoline, diesel etc). Allocation is shown in Figure 1a below.

As is commented in the discussion below, the pertinence of such an allocation methodology is questionable, as it implies that ”all products are considered equal”, i.e., that all products are equally desirable. This results in allocating a sizeable portion of the refinery emissions to streams that are residues or less desirable by-products.

In this work, we applied an alternative allocation methodology to that included in (NETL, 2008) based on the notional economic value of refinery products. Economic values were derived from the International Energy Agency Oil Market Reports for 2002-2005 (IEA, 2002-2005); note that the 2005 IEA Oil Market Report is the most recent report we could find that provides detailed product prices.

Allocation factors were determined based on the product price compared to crude oil. The IEA economic data analyzed reveal that over the period analyzed from 2002-2005, gasoline, diesel and kerosene prices were about 25% higher than crude oil prices. Fuel oil prices were about 25% lower than crude oil prices. Coke was assigned an economic allocation factor of zero. Light ends were assumed to have the same economic value of crude oil. Heavy ends were assumed to be composed of a combination of relatively low economic value bitumen and higher economic value products (such as lube oils) and were assumed to have, overall, the same economic value as crude oil. This is shown in Table 3.These normalized (with respect to crude oil) allocation factors were weighted with respect to their production volumes. Under this allocation method, gasoline, diesel and kerosene are attributed 85% of the refinery GHG emissions, whereas under the allocation methodology applied in (NETL, 2008), this value amounted to 80% only. In addition, under the economic allocation method, gasoline, diesel and kerosene have the same GHG value.

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Table 3. Allocation of refinery GHG emissions according to (NETL, 2008) and in this study (economic allocation)

		NETL (2008) Allocation by production volume						Economic Allocation		
Refinery Product	Amount Produced (1000 bpd)*	% Vol	% Vol	kgCO2e/ bbl**	kgCO2e/ MJ	kgCO2e/d	NETL Allocation of GHG emissions	Alternative Economic Allocation Factor***	Allocation factor weighted by production volumes	% Allocation
Gasoline	7'816.00	45%	77%	47.7	9.25	372823200	0.80	1.25	0.57	0.85
Diesel	3'954.00	23%		52.6	9.06	207980400		1.25	0.29	
Kerosene and Kerosene-based jet	1'611.00	9%		31.6	5.73	50907600		1.25	0.12	
Residual fuel oil	628.00	4%	23%	36.9		23173200	0.20	0.75	0.03	0.15
Coke	835.00	5%		43.9		36656500		0	0.00	
Light ends	1'684.00	10%		29.9		50351600		1	0.10	
Heavy ends	754.00	4%		69.4		52327600		1	0.04	
Total	17'282.00	100%	100%			794'220'100	1.0		1.14	1.0

* From Table 4-49 (NETL, 2008)

** From NETL (2008), Table 4-55

*** Normalized to crude oil (crude oil price = 1.0), Prices from IEA

Table 4. Calculation of GHG intensity of refining for gasoline, diesel and kerosene.

Refinery GHG emissions	Allocation to gasoline, diesel, and kerosene (x0.85)	Total Amount produced (gasoline, diesel, kerosene)	GHG intensity per unit of volume of gasoline, diesel, kerosene produced	GHG intensity of gasoline, diesel and kerosene per unit of energy
(kg CO2e/d)	(kg CO2e/d)	(bpd)	(kgCO2e/ bbl)	(kgCO2e/MJ)
794'220'100.00	676'554'866.76	13381	50'560.86	**9.40**

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Table 5. Sensitivity analysis of economic allocation using modified allocation factors

	Economic Allocation		
Refinery Product	Alternative Economic Allocation Factor***	Allocation factor weighted by production volumes	% Allocation
Gasoline	1.56	0.63	0.87
Diesel	1.56	0.32	
Kerosene and Kerosene-based jet	1.56	0.13	
Residual fuel oil	0.56	0.02	0.13
Coke	0	0.00	
Light ends	1	0.10	
Heavy ends	1	0.04	
		1.37	1.0

GHG intensity of gasoline, diesel and kerosene per unit of energy (kgCO2e/MJ)
9.74

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This determined allocation factor was applied to the total refinery GHG emissions and divided by the volumetric flow rate of gasoline, diesel and kerosene in order to derive the GHG intensity for these products. This is shown in Table 4.

Hence, we estimated refinery emissions as:

- Gasoline: 9.4 ± 20%gCO2e/MJ-fuel;
- Diesel: 9.4 ± 20%gCO2e/MJ-fuel;
- Kerosene and Kerosene-based Jet: 9.4 ± 20%gCO2e/MJ-fuel.

3.2.1. Data quality review & discussion

The refinery emissions assumed in (NETL, 2008) are listed below. Emission factors were derived using U.S. data (e.g., GaBi emission factors for power production, California data for flaring and venting, etc.)

- Acquisition of fuels used in refining (purchased power and steam; coal and natural gas; production of fuels at the refinery);
- Combustion of fuels at the refinery;
- Hydrogen production (Upstream emissions from natural gas feedstock to refinery; Emissions from steam methane reforming at refinery; Natural gas fuel and indirect (electricity) emissions for off-site hydrogen production); and
- Flaring, venting, and fugitive emissions.

(NETL, 2008) allocated emissions to the different refinery products according to their volumetric flow rates. Allocation is shown in Figure 1a below. The figures below show how emissions were allocated to refining products. The volumetric capacities of the individual unit operations were assigned to the seven product categories based upon the relative contribution of the throughput of that operation to the final product category (NETL, 2008). Figures 1 and 2 below show the calculations done in (NETL, 2008).

Figure 2 shows the results of the allocation. The figure shows that GHG emissions on a per unit finished fuel (barrel or MJ) for non-gasoline/diesel/kerosene are sizable when compared to those associated with gasoline, diesel and kerosene.

Figure 1 (part a) shows how energy and hydrogen use were attributed to the different unit operations and end products at the refinery. Figure 1 (part b) shows the underlying assumptions for each unit operation. Figure 1 (part c) shows the products categories and production volumes for 2005. The light ends category is composed of still gas, liquefied refinery gases (LRG), special naphtha, and petrochemical feedstocks. The heavy ends category is composed of asphalt and road oil, lubricants, waxes, and a miscellaneous fraction.

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Figure 1 (part a) shows that, in general, a large fraction of refinery flows (and thus energy use and emissions) are attributed to gasoline/diesel/kerosene, in proportion to their higher volumetric flows as refinery products (part c).

Figure 2 shows that non-gasoline/diesel/kerosene products have comparable GHG emissions per unit of fuel to gasoline/diesel/kerosene, and in the case of heavy ends, relatively higher emissions per unit of fuel. This means that the unit operations mainly processing heavy ends are deemed to have comparatively higher energy requirements & GHG emissions than unit operations processing the rest of the products, i.e., heavy ends are energy intensive. Indeed, the report shows that high energy requirements are associated with "Lubricants" operations (Table 4-43). However this cannot be supported for other heavy products such as asphalt or petroleum coke and is simply a result of the arbitrary allocation methodology used.

In conclusion, it is questionable to assign emissions based on volumetric flows as it implies that all products are considered equal and results in allocating a sizeable portion of the refinery emissions to streams that are clearly residues or less desirable by-products. Refineries are arguably mainly operating in order to produce light distillate products such as gasoline, diesel fuel and kerosene. In other words, high-value products are the reason why refining operations are in place and arguably they should be attributed the bulk of the emissions. Hence, it makes little sense, for example, to allocate emissions to coke in proportion to the volumetric production of coke, as coke is a relatively undesired co-product, i.e., it has low economic value. This attribution method will hence result in lower than expected GHG intensities for gasoline, diesel and kerosene.

It must also be pointed out that the refinery product slate assumed in NETL is typical of the USA. In most of the rest of the world refining activities tend to be less energy-intensive because of sizeable heavy fuel oil markets. This partly compensates the underestimation mentioned above for transport fuels.

For the purpose of this study, and for the reasons outlined above, an economic allocation method was used, and not the allocation based on volumetric flow rates in refinery operations used in (NETL, 2008).

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Figure 1: Allocation of refining energy use and hydrogen production/consumption to refining product fractions and underlying assumption on unit operations' contribution to end products (NETL, 2008)

Figure 1a: Allocation of volumetric throughput to end products (NETL, 2008)

Figure 4-8. Percent of Volumetric Throughput Allocated to End Products

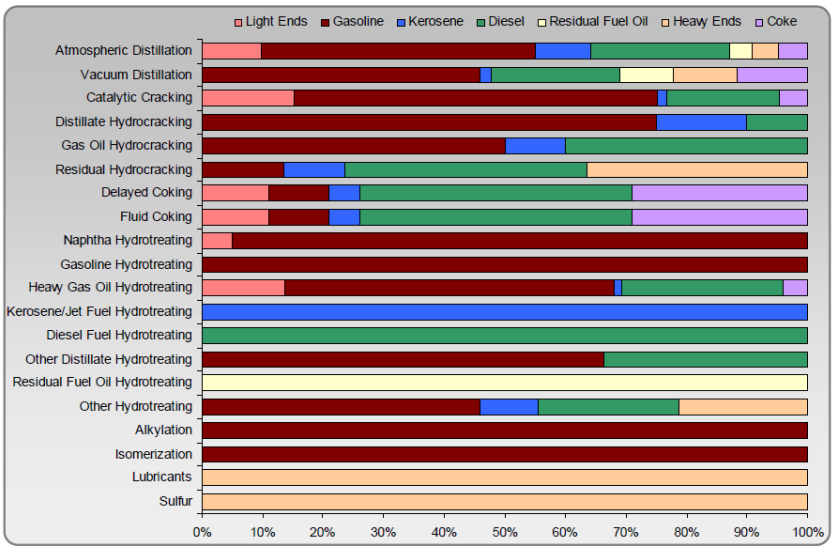

Figure 1b: Underlying assumptions to Figure 1a (NETL, 2008)

Table 4-52. Summary of Unit Operation Contribution to End Products

	Gasoline	Diesel	Kerosene/ Kerosene-Based Jet Fuel	Residual Fuel Oil	Coke	Light Ends	Heavy Ends
Atmospheric Distillation	Relative to final product slate						
Vacuum Distillation	Equal to catalytic cracking throughput contribution for Gasoline, Diesel or Kerosene plus the remainder (after fuel oil, coke, heavy ends is assigned) ratioed to Gasoline, Diesel and Kerosene relative to respective throughput contribution of coking units			Equal to final product slate			Equal to final product slate
Catalytic Cracking	60% of throughput	25% of diesel produced	5% of kerosene produced		All catalyst coke	Balance	
Distillate Hydrocracking	75%	10%	15%				
Gas Oil Hydrocracking	50%	40%	10%				
Residual Hydrocracking	Balance	40%	10%				51.3 Mbpd
Delayed Coking	10% of throughput	45% of throughput	5% of throughput		All marketable coke distributed based on throughput	Balance	
Fluid Coking							
Naphtha Hydrotreating	95% of throughput					5% of throughput	
Reformer Feed Hydrotreating*	95% of throughput*					5% of throughput*	
Gasoline Hydrotreating	All						
Heavy Gas Oil Hydrotreating	1,850 kbbl/day is catalytic cracker feed hydrotreating and is distributed as in catalytic cracking; remainder to diesel fraction						
Kerosene/Jet Fuel Hydrotreating			All				
Diesel Fuel Hydrotreating		All					
Other Distillate Hydrotreating	Relative to final product slate						
Residual Fuel Oil Hydrotreating				All			
Other Hydrotreating	Balance relative to final product slate						115 Mbpd
Catalytic Reforming*	95% of throughput*					5% of throughput*	
Alkylation	All						
Isomerization	All						
Lubricants							All
Sulfur							All

* Allocations for reformer feed hydrotreating and catalytic reforming include only energy requirements remaining after assigning energy to the hydrogen pool

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Figure 1c: Amount produced in each product category in 2005 (NETL, 2008) and calculated percentages

Table 4-49. Product Categories and Amount Produced in 2005

Product Category	Amount Produced (thousand bpd)	% Vol	% Vol
Gasoline	7,816	45%	77%
Conventional Gasoline	7,794		
Aviation Gasoline	22		
Diesel	3,954	23%	
Conventional Diesel (≤500 ppm sulfur)	2,933		
All Other Diesel	1,022		
Kerosene and Kerosene-Based Jet Fuel	1,611	9%	
Kerosene-Based Jet Fuel	1,546		
Kerosene	66		
Residual fuel oil	628	4%	23%
Coke	835	5%	
Light ends	1,684	10%	
Heavy ends	754	4%	
TOTAL	17282	100%	100%

Figure 2: Refining emissions allocated to different products [(NETL, 2008), Table 4-55]

Source	Gasoline	Diesel	Kerosene & Kerosene-type Jet Fuel	Residual Fuel Oil	Coke	Light Ends	Heavy Ends
GWP in CO_2E (kg/bbl Refined Product)	**47.7**	**52.6**	**31.6**	**36.9**	**43.9**	**29.9**	**69.4**
Refinery Fuels Combustion	31.5	32.8	19.8	23.7	31.3	20.7	48.5
Purchased Steam and Electricity	5.86	6.10	3.67	4.41	5.81	3.84	9.00
Acquisition of Natural Gas & Coal	1.12	1.16	0.70	0.84	1.11	0.73	1.72
Acquisition of Refinery-Produced Fuels	4.42	4.60	2.77	3.32	4.38	2.89	6.79
Hydrogen Production*	4.35	7.55	4.43	4.32	0.93	1.54	2.77
Flaring, Vented & Fugitive	0.40	0.41	0.25	0.30	0.39	0.26	0.61

GHG Intensity of refinery operations for gasoline, diese and kerosene according to (NETL, 2008)

Unit	Gasoline	Diesel	Kerosene & Kerosene-type Jet fuel
kg CO2e/bbl	47.7	52.6	31.6
kg CO2e/MMBtu (LHV)	9.8	9.5	6.0
gCO2e/MJ	9.25	9.05	5.73

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(LCFS, 2009a) and (LCFS, 2009b) calculated refining emissions that are considerably higher than those in this study, namely 13.72 gCO2e/MJ attributable to gasoline and 11.41 gCO2e/MJ attributable to diesel. Refinery efficiency was calculated to be 84.5% for gasoline and 86.7% for diesel. In order to derive a GHG emissions value, (LCFS, 2009a) and (LCFS, 2009b) adjusted the total fuel usage in the refinery by applying the refining efficiency factor (for gasoline or diesel); they also determined the mix of fuels required to produce 1MM BTU of gasoline/diesel. Hence, they derived, for each fuel type, the BTU of fuel/BTU gasoline (or diesel) used in a refinery (e.g., x BTU natural gas/ BTU gasoline, etc.). These values were then adjusted (slightly increased) to reflect WTT losses. To summarize, the study assessed the mix of fuels (adding up to 100%) that make up 1MM BTU of gasoline (or diesel), adjusted (increased) these values to account for the efficiency of refining, adjusted (increased) these values to account for upstream losses, and thus determined the final fuel mix "contained" in 1 MMBTU of gasoline (diesel). Emission factors for the different fuels in the mix were applied to derive the GHG intensity value for gasoline (diesel).

This approach is very different from the approach in (NETL, 2008) and in this study. In (NETL, 2008), which was used in this study, the calculation is based on the actual amount of reported (in EIA) values of fuel use in refineries; the GHG emissions associated with this fuel use is then allocated to the refinery products using a certain allocation methodology (discussed above). However, (LCFS, 2009a) *and* (LCFS, 2009b) *do not conduct any allocation*; they rather estimate *how much fuel went into each unit of energy of gasoline/diesel* and calculate GHG emissions based on this. *We believe that this leads to an over-estimation of emissions, because some of the refinery inputs (fuels) that were used to produce gasoline were also used to produce diesel and other refinery products and this is not taken into account in the methodology applied in* (LCFS, 2009a) *and* (LCFS, 2009b). I.e., if this method were used to calculate the GHG intensity of each fuel produced in the refinery, and this value were mutiplied by the amount of such fuel produced, then the total refinery GHG emissions calculated would be larger than the actual GHG emissions produced by the refinery. We believe that this is the case but cannot prove it, as (LCFS, 2009a) *and* (LCFS, 2009b) do not provide GHG intensity data for all other refinery products.

Hence, as a result of the detailed listed in the discussion above, we believe that the approach followed in (LCFS, 2009a) *and* (LCFS, 2009b) *might lead to over-.estimation of GHG emissions from refining as it is not based on actual refinery GHG Emissions*.

3.2.2. Estimated Uncertainty

We have not assessed the GHG emissions associated with refineries outside the U.S. and Europe. Because of this, it is difficult to assign an uncertainty value to the emissions associated with refining.

With regards to the uncertainty associated with assumptionn used in the economic allocation calculations, it is important to note that the oil and oil products prices can be subject to wide changes; the economic allocation in this study was based on IEA Oil Market Reports for the

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years from 2002-2005. Based on these data, the approximate economic values indicated in Table 3 were used. If the economic allocation factors for gasoline, diesel, and kerosene are changed to 1.56 (an increase of 25% with respect to the 1.25 used in the calculations) and the factor for residual fuel oil is changed to 0.56 (a reduction in 25% from the 0.75% used in the calculations), the resulting carbon intensity of refining is 9.74 gCO2e/MJ, an increase of only 3.6% with respect to the calculated 9.4 gCO2e/MJ. This is shown in Table 5.

Based on the considerations above, an uncertainty value of 20% was tentatively assessed.

3.3.Fuel Use

Emissions from fuel use are based on stoichiometric (i.e., theoretical) calculations based on the composition of the fuel. This calculation does not take into account the efficiency or combustion mechanism that takes place in the engine of the vehicle. Hence, emissions of the following are *not* included: products of incomplete combustion (such as CO), combustion by-products (such as CH4), and nitrous and nitrogen oxide emissions (N2O, NOx) associated with the nitrogen content of the biomass. This is the same approach used in the RSB GHG Calculation methodology for biofuels. The contribution of CH4 and N2O emissions from real combustion is small compared to CO2 emissions (see Table 6).

Emissions from use of the fuel in a vehicle engine were taken from (JEC, 2007), which calculates CO2 emissions based on the content of carbon molecules in the fuel and assuming total (perfect) combustion of the carbon to CO2. The values are: 73.3 gCO2e/MJ-fuel; Diesel: 73.2 gCO2e/MJ-fuel. In this study, we applied the value for Diesel to Kerosene and Kerosene-based Jet.

Hence, emissions from fuel use are:

- Gasoline: 73.3 ± 0.3 gCO2e/MJ-fuel;
- Diesel: 73.2 ± 0.3 gCO2e/MJ-fuel;
- Kerosene and Kerosene-based Jet: 73.2 ± 0.3 gCO2e/MJ-fuel.

3.3.1. Data quality review & discussion

(NETL, 2008) calculated emissions from use of the fuel in a vehicle engine, taking into account the characteristics of the engine. Results are listed in Table 6. Results are similar enough to those obtained by (JEC, 2007) that the values obtained in the latter study are considered of good enough quality.

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Table 6: Emissions per unit of fuel consumed [(NETL, 2008), Table 6-3]

GHG emitted	Unit	Gasoline	Diesel	Kerosene & Kerosene-type Jet fuel
CO2	kg/MMBtu (LHV)	75.0	76.6	77.1
CH4		4.88E-03	8.00E-05	5.00E-04
N2O		4.99E-03	1.75E-04	2.00E-03
CO2e		76.6	76.7	77.7
CO2e	gCO2e/MJ	72.7	72.7	73.7
% CO2e from CO2		97.9%	99.9%	99.2%
% CO2e from N2O & CH4		2.1%	0.1%	0.8%

For comparison, the California Low Carbon Fuel Standard cites 74.9 gCO2e/MJ for California Ultra Low Sulfur Diesel fuel combustion emissions (LCFS, 2009a). For Gasoline (CARBOB), carbon-content (stoichiometric) calculations of CO2 emissions yielded 72.91 gCO2/MJ (LCFS, 2009b).

3.3.2. Estimated Uncertainty

Using the methodology shown above, i.e., calculations of CO2 emissions based on the carbon content of the fuel, there is little uncertainty associated with this estimate, since the carbon content of the various fuels is a known property. For example, under the LCFS the value for gasoline is 72.91 gCO2/MJ whereas the value calculated by (JEC, 2007) is 73.3. Based on this, an uncertainty of ±0.3 gCO2/MJ was assessed.

3.4.Transport & Distribution of Crude Oil and Finished Fuel

The transport steps add small but non-negligible amounts of GHG emissions to the lifecycle emissions of fossil fuels. There are two main transport steps.

The transport steps include transport of crude oil, other hydrocarbons, natural gas liquids, and unfinished oils to refineries as raw material or energy inputs. The next step includes transporting the finished fuel to bulk storage, storage of product at terminals or at the airport, and fueling of the vehicle or aircraft.

The main emissions are associated with the energy consumption of transport operations via pipeline, seaborne or inland water carrier (tanker), railroad, or tank truck. Pipeline transport requires electricity and tanker/railroad/truck transport have fuel requirements.

There are also fugitive and venting emissions associated with product storage and refueling operations but these are very low in GHG terms. (JEC, 2008) calculated crude oil transport

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emissions of 0.9 gCO2e/MJ and finished fuel transport & distribution emissions of 1.0 gCO2e/MJ.

(NETL, 2008) calculated crude oil transport emissions of 1.2-1.3 gCO2e/MJ for gasoline, diesel, and jet kerosene and finished fuel transport & distribution emissions of 0.9-1.0 gCO2e/MJ.

(IEA, International Energy Agency, Statistics, Oil, Year 2008, 2008) statistics include information on the volumes of crude oil and refinery products produced, exported and consumed by country. The 23 main crude oil producing countries were assessed. It was determined that about 60% of total crude oil produced is exported. Of the gasoline, diesel, and kerosene produced, about 14% are exported and the rest is used in transport.

Based on these numbers, it was assumed that the average barrel of crude oil "travels" via pipeline from the producing country's wells to a port, is then shipped to a foreign port, and is finally transferred via pipeline, railcar, and truck to a refinery. Given the large amount of crude oil that is exported, relatively long travel distances were assumed.

Gasoline, diesel and kerosene are assumed to be consumed in the country. It was assumed that the average barrel of gasoline, diesel or kerosene travels via pipeline, railcar and truck to a distribution center where it is stored, and from there to the fueling station. Transport distances were assumed to be smaller because the fuel is assumed to travel within the country of production only. Venting and fugitive emissions from storage and refueling operations were disregarded because such emissions comprise only about 0.5% of transport emissions as determined from (NETL, 2008).

It must be noted that the uncertainty assosciated with the estimated transport emissions is assumed to be high.

We have assumed ± 30% on each of the transport elements.

Table 7 outlines the assumptions made and shows the caculations.

Based on that table, the *total emissions* associated with transport are:

- Gasoline: 1.9 ± 0.2 gCO2e/MJ-fuel;
- Diesel: 1.9 ± 0.2 gCO2e/MJ-fuel;
- Kerosene and Kerosene-based Jet: 1.9 ± 0.2 gCO2e/MJ-fuel.

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Table 7: Transportation of crude oil and transportation & distribution of finished fuel – Assumptions in this study

Item	Medium	Distance (km)	Energy use (BTU/ton-km)*	Fuel Source	CO2 (kg/ MMBtu)*	CH4 (kg/ MMBtu)*	N2O (kg/ MMBtu)*	Energy use (BTU/ton)	Energy use (BTU/bbl)	CO2 (kg/ton)	CH4 (kg/ton)	N2O (kg/ton)	CO2e (kg/ton)	CO2e (g/MJ)
Crude oil transport	Pipeline	150	156	Electricity	217	0.251	0.003	23353	3336	5.1	5.9E-03	5.9E-05	5.2	0.12
	Tanker	20000	24**	Heavy fuel oil	79	0.006	0.002	480838	68691	37.9	2.8E-03	9.6E-04	38.2	0.91
	Pipeline	250	156	Electricity	217	0.251	0.003	38922	5560	8.4	9.8E-03	9.8E-05	8.7	0.21
	Railroad	0	202	Diesel fuel	68	0.005	0.002	0	0	0.0	0.0E+00	0.0E+00	0.0	0.00
	Truck	0	492***	Diesel fuel	68	0.005	0.002	0	0	0.0	0.0E+00	0.0E+00	0.0	0.00
Subtotal crude oil transport														**1.25**
Finished fuel transport	Pipeline	500	156	Diesel fuel	217	0.251	0.003	77844	11121	16.9	2.0E-02	2.0E-04	17.4	0.42
	Railroad	250	202	Diesel fuel	68	0.005	0.002	50449	7207	3.4	2.7E-04	8.7E-05	3.5	0.08
	Truck	150	492***	Diesel fuel	68	0.005	0.002	73832	10547	5.0	3.9E-04	1.3E-04	5.1	0.12
Subtotal finished fuel transport														**0.62**
Total Transport														**1.87**

*(NETL, 2008) unless otherwise noted
**5.5 Btu per barrel-nautical mile (NETL, 2008)
***Engineering estimate 35Ldiesel/100km/25 ton = 481 BTU/ton-mi
‡ Based on heavy fuel oil emission, adjusted

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3.4.1. Data quality review and discussion

Given the large uncertainties associated with crude oil and finished product transport, a value between 0.9- 1.2 gCO2e/MJ is deemed appropriate for crude oil transport operations and a value of 0.9-1.2 gCO2e/MJ is deemed appropriate for fuel transport operations. Emissions associated with transportation & distribution of crude oil and finished fuel were estimated using assumed distances and transporation modes, and using published emission factors.

3.4.2. Estimated Uncertainty

There is a large uncertainty associated with global transportation emissions for crude oil and finished fuel. However, the values for each of these categories are expected to fall roughly within the range indicated above. Therefore, we estimated an uncertainty of 0.2 (or 30%) for each of these values.

(LCFS, 2009a) and (LCFS, 2009b) estimated crude transport emissions as 1.14 gCO2e/MJ and fuel transport emissions as 0.36 gCO2e/MJ for gasoline (LCFS, 2009b) and 0.33 for diesel (LCFS, 2009b) transport – these results are in agreement with the results of this study.

4. Uncertainty

The uncertainty associated with each portion of the calculation has been summarized in the Table 8. The uncertainty is between 2.1 and 2.6 gCO2e/MJ.

Table 8: Summary of estimated emissions and associated estimated uncertainty

Lifecycle stage	*Estimated emissions (gCO2e/MJ)*			*Estimated Uncertainty (gCO2e/MJ)*		
	Gasoline	*Diesel*	*Jet Kerosene*	*Gasoline*	*Diesel*	*Jet Kerosene*
Crude oil production	5.6	5.6	5.6	1.7	1.7	1.7
Crude oil transport	1.3	1.3	1.3	0.3	0.3	0.3
Fuel production	9.4	9.4	9.4	1.9	1.9	1.9
Finished fuel transport	0.6	0.6	0.6	0.2	0.2	0.2
Use	73.3	73.2	73.2	0.3	0.3	0.3
Total	90.1	90.0	90.0	2.6*	2.6*	2.6*
Rounded	90	90	90	3	3	3

*Note: Total uncertainty calculated as the square root of the sum of the squares. I.e., for the sum (A+B+C), uncertainty $\sigma = \sqrt{A^2 + B^2 + C^2}$.

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References

BP. (2010). *Statistical Review of World Energy.* British Petroleum , http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622.

CAPP. (2010). *Crude Oil: Production, Forecast and Pipelines; Canadian Association of Petroleum Producers; June 2010.*

IEA. (2005). *International Energy Agency, Oil Market Report, December 2005.* http://omrpublic.iea.org/omrarchive/13dec05full.pdf.

IEA. (2008). *International Energy Agency, Statistics, Oil, Year 2008.* http://iea.org/stats/index.asp.

JEC. (2007). *Well-to-Wheels analysis of future automotive fuels and powertrains in the European context, Well-to-Tank Report Version 2c, Appendix 1, March 2007.* http://ies.jrc.ec.europa.eu/jec-research-collaboration/downloads-jec.html.

JEC. (2008). *Well-to-Wheels analysis of future automotive fuels and powertrains in the European context, WELL-TO-TANK Report Version 3.0 November 2008.* http://ies.jrc.ec.europa.eu/jec-research-collaboration/downloads-jec.html.

Larive. (2011). *Personal communication, January-April, 2011; data calculated in the context of the 2011 update of JEC WTW study.*

LCFS. (2009b). *Detailed CA-GREET Pathway for California Reformulated Gasoline Blendstock for Oxygenate Blending (CARBOB) from Average Crude Refined in California, February 28, 2009.* http://www.arb.ca.gov/fuels/lcfs/022709lcfs_carbob.pdf.

LCFS. (2009a). *Detailed California-Modified GREET Pathway for Ultra Low Sulfur Diesel (ULSD) from Average Crude Refined in California, February 28, 2009.* http://www.arb.ca.gov/fuels/lcfs/022709lcfs_ulsd.pdf.

NETL. (2008). *Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emission of Petroleum-Based Fuels", November 2008.* U.S. National Technology Energy Laboratory, DOE/NETL-2009/1346.

NOAA. (2010). *Global gas flaring estimates. National Oceanic and Atmospheric Administration.* http://www.ngdc.noaa.gov/dmsp/interest/gas_flares.html.

OGP. (2005). *Environmental performance in the E&P industry, 2005 data. International Association of Oil & Gas Producers (OGP) report 383, October 2006.* www.ogp.org.uk.

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Annex 1: Unit Conversions & GWP

Unit Conversions

1	Equals		Product	Source
BTU	1054.35	J	-	
bbl	158.9873	L	-	
kWh	3414.426	BTU	-	
toe	7.33	boe	Crude oil	http://www.spe.org/industry/reference/unit_conversions.php
	41.87	GJ	Crude oil	Wiki
bbl	5.8	MMBTU	Crude oil	
toe	8.45	boe	gasoline	http://www.mbendi.com/indy/oilg/p0020.htm
	7.5	boe	diesel	http://www.mbendi.com/indy/oilg/p0020.htm
	7.9	boe	kerosene	Jean Francois Larive, personal communication
bbl	4.89	MMBtu LHV	gasoline	NETL 2008 (Table I-1)
	5.51	MMBtu LHV	diesel	NETL 2008 (Table I-1)
	5.23	MMBtu LHV	kerosene	NETL 2008 (Table I-1)
bbl	5155.772	MJ LHV	gasoline	Calc'd
	5809.469	MJ LHV	diesel	Calc'd
	5514.251	MJ LHV	kerosene	Calc'd
ton	43.56627	GJ	gasoline	Calc'd
	43.57101	GJ	diesel	Calc'd
	43.56258	GJ	kerosene	Calc'd
	43.56662	GJ	Average	Calc'd

Global Warming Potentials

GHG	GWP (IPCC, 2007)
CO2	1
CH4	25
N2O	298

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Annex 2: Peer Review

A Draft version of this document was sent to individual experts belonging to the RSB GHG Expert Group, three of which accepted to review the document (and one of which shared the Draft document with four additional experts outside the RSB GHG Expert Group). Peer review results are presented in this section, as well as the RSB Secretariat response to the comments received and resulting modifications to the Draft document.

The Secretariat would like to express its gratitude to the experts, who provided extremely valuable comments and feedback.

Individual from RSB GHG EG who accepted to peer review the work	**Main comments about DRAFT Version**	**RSB Secretariat response to comments and *modification to DRAFT document***
Rick Malpas Project Leader, Greenhouse Gas Intensity Analysis Team Shell Research Ltd	I was in general agreement with the document. The carbon intensities, especially for gasoline and diesel seem about right when you consider the EU and US values and your use of NETL data leads to a good level of transparency in how you derive them. It was good to see that you have kept things simple in going for general default values rather than getting into the debate over individual values that is currently going on in the EU. As you say, these defaults can be monitored and updated as necessary.	None
Kevin Fingerman PhD Candidate Energy & Resources Group University of California Berkeley	In general agreement with the methodology	None

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Individual from RSB GHG EG who accepted to peer review the work	**Main comments about DRAFT Version**	**RSB Secretariat response to comments and *modification to DRAFT document***
Jesper Hedal Kløverpris, PhD LCA Specialist Novozymes A/S Björn Pieprzyk Energy consultant era energy research architecture Keith Kline Environmental researcher Oak Ridge, TN Steffen Mueller, PhD Principal Research Economist University of Illinois at Chicago Blake A. Simmons, PhD Deputy Director Sandia National Laboratories, CA	[…] this scope omits important dimensions of fossil fuel impacts, ranging from the direct effects of exploration and discovery phases (which are increasingly impacting sensitive and remote regions such as the western Amazon, the Arctic, boreal forests and coastal wetlands) to the issue of identifying those fossil fuels that are more likely to be replaced by biofuels *It is recommended that the document indicate the frequency of future updates and consider expanding the scope of the analysis to calculate the impacts of fossil fuels using criteria consistent with those used for biofuels (e.g. quantifying all direct effects and emissions, including those for exploration phases).*	The Steering Board decision of November 2010 was to calculate the average, rather than the marginal, fossil fuel baseline. Ideally, all the direct GHG emissions associated with crude oil exploration & production would be included in the calculation; unfortunately, we could not find global, country-specific O&P GHG emission factors that took such impacts into consideration. We do not think that the GHG factors listed in (NETL, 2008) take such impacts into consideration. At this point, the Steering Board has not decided on the frequency of re-calculation; this subject will be taken up in an upcoming in-person meeting; *an explanation to this effect has been added to the document.*
Kløverpris, Pieprzyk, Kline, Mueller, and Simmons (Cont'd)	It is mentioned that an expert in the oil & gas industry and in LCA of fossil fuels and biofuels has guided the RSB analysis of the fossil fuel baseline *For the sake of transparency, it is recommended that the name or at least the affiliation of this individual is mentioned.*	*The name of the expert has been indicated.*
Kløverpris, Pieprzyk, Kline, Mueller, and Simmons (Cont'd)	The analysis arrives at a carbon intensity of 90 g CO2e/MJ for gasoline and diesel. This is somewhat lower than the values in the California Low Carbon Fuel Standard (LCFS), which applies 96 g CO2e/MJ for gasoline, and the US Renewable Fuel Standard (RFS), which applies 93 g CO2e/MJ for gasoline. *It is recommended that these differences are discussed in the RSB document.*	A discussion was added to the Crude oil production section and the Transport section, and a detailed discussion was added to the Refining section. The Use section already addressed the LCFS

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Kløverpris, Pieprzyk, Kline, Mueller, and Simmons (Cont'd)	The authors mention that crude oil from Canadian tar sands is assumed to make up 55% of Canadian crude oil production. *We recommend that the authors state explicitly whether the carbon intensity for Canadian tar sands includes considerations on direct land use change and recovery operations after extraction.*	(NETL, 2008) derived GHG emissions profiles for Canadian conventional crude and tar sands crude. For tar sands crude oil production, the GHG intensity values "were derived using actual emissions reported by two primary producers, Imperial Oil and Syncrude, and their estimated 2005 production rates, as reported by the respective operators". *We could not assess whether these values included considerations on direct and use change and recovery operations, as we did not have time to contact the above-mentioned producers.*
Kløverpris, Pieprzyk, Kline, Mueller, and Simmons (Cont'd)	It appears that crude oil from Canadian tar sands is the only type of unconventional fossil fuels considered in the analysis. This may be because other unconventional fuels are „hiding" between the numbers or because 2009 production levels were not considered high enough to affect the global average carbon intensity. Never-the-less, *we recommend that the RSB addresses this explicitly in their analysis*. Were technologies such as shale oil extraction, coal-to-liquids, and gas-to-liquids considered? Besides this clarification, *we recommend that the RSB gives consideration to the future production of unconventional fossil fuels and its implications for the global average carbon intensity of gasoline, diesel, and kerosene.*	We acknowledge the importance of unconventional crude oil production on environmental impacts and GHG emissions and have added a statement addressing the need to understand unconventional fossil fuel production and its potential impacts on GHG emissions going forward. We appreciate the reference provided.

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Kløverpris, Pieprzyk, Kline, Mueller, and Simmons (Cont'd)	The authors discuss the two data sets from NETL (2008) and OGP (2005). *The authors may consider discussing the level of independence for these two data sources.* It is mentioned that the data from OGP (2005) is significantly lower than the data from NETL (2008). However, the actual emissions may in some cases be even higher than implied by NETL (2008). We took a closer look at the flaring data published by the National Oceanic and Atmospheric Administration (NOAA 2010). For some countries (like Russia, Libya, and Qatar), *the flaring emissions alone* (not including venting emissions or other production emissions) come very close to the *total GHG emissions* from crude oil production listed in Table 2a in the RSB document (see spreadsheet attachment for calculations). For other countries (like Iraq and Iran), flaring emissions alone (again based on NOAA, 2010) exceed the total production emissions in Table 2a (see spreadsheet attachment). We think this illustrates that production emissions may be significantly underestimated for several countries.	*A discussion on F&V was added in the Production section, including some of the data provided by Kloverpris et al.*

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Kløverpris, Pieprzyk, Kline, Mueller, and Simmons (Cont'd)	As for venting, we determined the average venting-to-flaring ratio based on F&V data in NETL (2008)2. We combined this average ratio (0.25) with the gas flaring data from NOAA (2010) and the crude oil production data from BP (2010) to obtain an alternative estimate of venting emissions (see spreadsheet attachment for details). For most of the countries investigated, this resulted in F&V emissions far beyond the total production emissions listed in Table 2a. We acknowledge that this procedure is crude but it illustrates that venting emissions can be very important. On this basis, *we suggest that a default venting-to-flaring ratio of at least 0.25 is applied unless measured venting data is available for the oil production being analyzed*. Concerns about F&V emissions are underscored by a recent study from Rice University3 that emphasizes the need to implement technologies to measure venting emissions worldwide. In this report, it is stated that "Currently, satellite technology is not capable of detecting associated gas volumes from venting, which may be significant in some producing regions" and "...there needs to be a concerted effort to estimate gas venting, potentially a far more serious global environmental threat [than flaring]".	See comment above.
Kløverpris, Pieprzyk, Kline, Mueller, and Simmons (Cont'd)	The authors use emissions data for US refining as a proxy for the average emissions from global refining. However, only a fraction of the global crude oil production is refined in the US. *It is suggested to include considerations on the implications of the use of US data as a proxy for the world average. Does it increase or decrease the GHG emissions?*	It was already included in the discussion that we believe that U.S. GHG emissions associated with refining operations tend to be slightly higher than in the rest of the world given that U.S. refineries are set up to produce a mix of products that requires higher energy inputs.

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Kløverpris, Pieprzyk, Kline, Mueller, and Simmons (Cont'd)	As the authors point out themselves, the volumetric allocation procedure used by NETL (2008) is clearly problematic. Ideally, a system expansion or displacement methodology should be used. This would require that the „determining co-product" from the refinery is identified, i.e. the product that is the main reason for production. The remaining co-products should then be analyzed in terms of what they displace in the marketplace. This is the same procedure which is applied for corn ethanol. Ethanol is the determining co-product and the DGS is analyzed based on its feed substitution value. However, this is admittedly difficult to do for a refinery since there is likely more than one co-product determining production (as also suggested by the authors). Furthermore, it may be difficult to determine what non-determining co-products such as coke are displacing on the market. Or put differently, it may be difficult to determine which product that would replace coke if less of this refinery co-product became available. In light of these difficulties, *RSB is encouraged to adopt an economic allocation procedure because this gives a better indication of the determining co-product(s) from the refinery*.	We have used an economic allocation methodology instead of the original volumetric/unit operation allocation conducted by (NETL, 2008) and indeed arrived at emission GHG intensities; however, the differences are minor (except for kerosene).
Kløverpris, Pieprzyk, Kline, Mueller, and Simmons (Cont'd)	We suggest using a lower case „2" in CO2 and to separate „g" and „CO2e" in the unit „g CO2e".	Minor formatting suggestion. Will be implemented if time permits.
Kløverpris, Pieprzyk, Kline, Mueller, and Simmons (Cont'd)	Please, correct (NETL, 2009) to (NETL, 2008)	*We have made this change*
Kløverpris, Pieprzyk, Kline, Mueller, and Simmons (Cont'd)	Please, mention the factor used for conversion of barrels (in BP 2010) to tons (in Table 2a).	*We have included a Unit Conversions section*

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Kløverpris, Pieprzyk, Kline, Mueller, and Simmons (Cont'd)	Please, include PE International (2008) in the reference list.	The reference and full profiles are included in (NETL, 2008). Hence, (NETL, 2008) is the source for PE International (2008)
Kløverpris, Pieprzyk, Kline, Mueller, and Simmons (Cont'd)	Please, indicate the source(s) used for the transport emissions in Table 5.	*We have provided clarification on the source of emission factors used in this section*; we hope that this serves as sufficient clarification.
Kløverpris, Pieprzyk, Kline, Mueller, and Simmons (Cont'd)	Please, see remaining minor comments/suggestions in the attached, marked up document.	We believe that these have been addressed.

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