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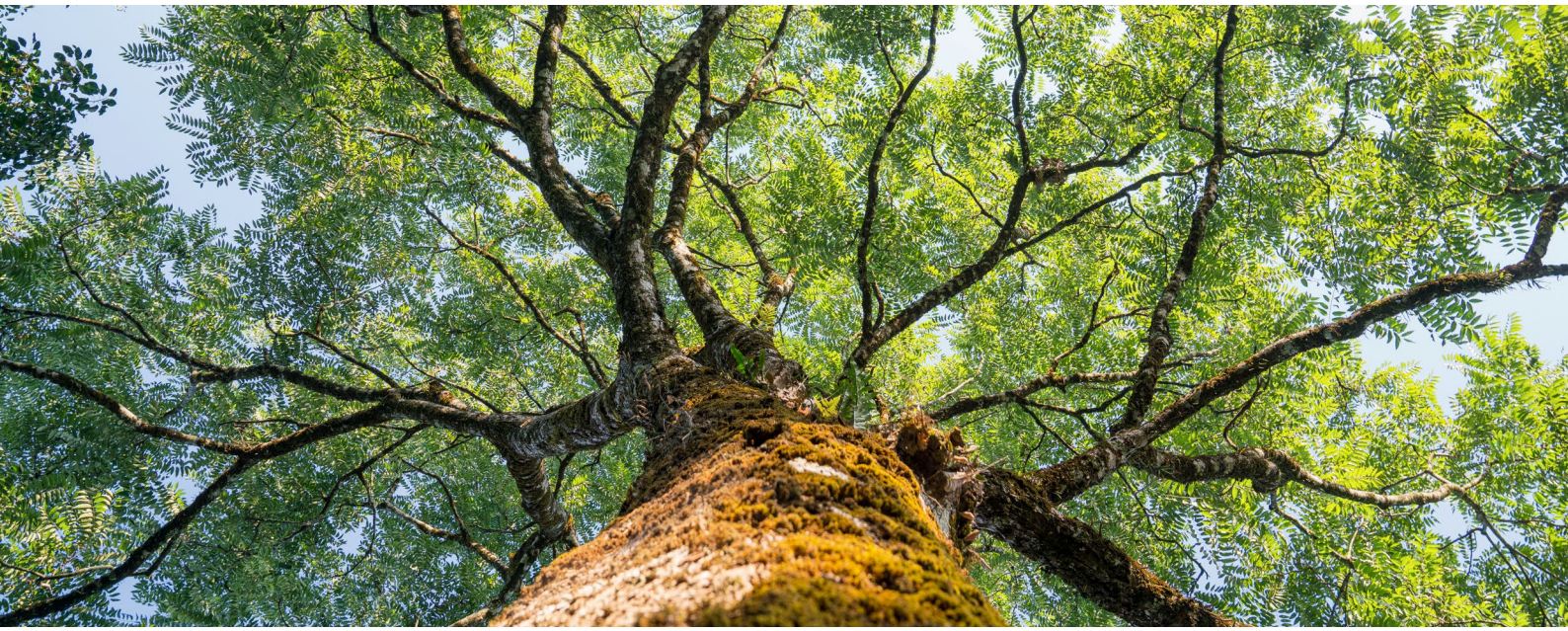

Emissions Guidebook

Part 3: Reference definitions and data

Version 1.0

Center of Emissions Excellence

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About the Emissions Guidebook

Purpose

Greenhouse gas (GHG) emissions have emerged as a critical metric for governments and investors given an ever-growing focus on establishing transparent frameworks for measuring, reporting, quantifying and ultimately reducing GHG emissions globally. It is of utmost importance that methodologies used by different entities are transparent and clear so different studies and emission estimates can be compared on a like-for-like basis. Without this transparency, emissions estimates have limited utility in the marketplace. The Emissions Guidebook is an evergreen document that provides the market with unparalleled transparency into S&P Global Energy' approach, methodology and key assumptions behind our emissions work. We hope this document can contribute to advancing consistency in GHG emissions accounting.

Context

The Emissions Guidebook is a product of the S&P Global Energy Center of Emissions Excellence. The "Center" is a dedicated team of carbon accounting specialists focused on ensuring consistency, transparency and credibility of emissions data across any emissions offerings.

About S&P Global Energy

At S&P Global Energy, our complete view of global energy and commodity markets enables our customers to make decisions with conviction and create long-term, sustainable value.

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Table 1

Mass conversion

Source unit	Equals or denotes
1 kilogram (kg)	2.205 pounds
1 metric ton (t)	1,000 kg
1,000 grams	1 kg
1 Mt	1 mega metric ton
1 kt	1 kilo metric ton

Table 2

Volume conversion

Source unit	Equals or denotes
1 m^3	35.31 ft^3
1 Mcf	1,000 ft^3
1 MMcf	1,000,000 ft^3
1 gallon (gal)	3.785 liters
1 barrel (b)	42 gal
1 m^3	6.2898 barrel

Table 3

Energy conversion

Source unit	Equals or denotes
1 MJ (Megajoule)	1,000,000 J
1 MMBtu	1,000,000 Btu
1 MJ	1055 MMBtu
1 MWh	3600 MJ
1 GJ	1000 MJ

Source: S&P Global Energy.

Heating values

Higher and lower heating value definitions

Higher heating values or gross heating values are obtained by assuming that all water in the combustion products is in liquid form, therefore resulting in more energy availability in the fuel (as the energy to condense the water vapor is included as available energy). In reality, most combustion processes do not condense the water vapor in the exhaust. The lower heating value or net heating value assumes that the water remains vapor in the exhaust. In the work that the Center of Emissions Excellence does for supply chain emission accounting, lower heating values are used to represent carbon intensities of energy commodities such as natural gas, crude oil and natural gas liquids.

Complete combustion and enthalpies of formation

Energy content of different compounds can be calculated from enthalpies of formation for each compound and combustion pathways. Enthalpy of formation is the energy required to form a compound in a chemical reaction such as combustion process. Complete combustion (whereby all carbon molecules are converted to carbon dioxide and all hydrogen molecules are converted to water vapor in the combustion process) was assumed according to equations listed in Table 4. Enthalpies of formation and molecular weights of various compounds are listed in Table 5.

Table 4

Complete combustion pathways for various hydrocarbons
Combustion equations, assuming complete combustion

1 H_2	+	0.5 O_2	+	1.88 N_2	=	0 CO_2	+	1 H_2O	+	1.88 N_2
1 CH_4	+	2 O_2	+	7.52 N_2	=	1 CO_2	+	2 H_2O	+	7.52 N_2
1 C_2H_6	+	3.5 O_2	+	13.16 N_2	=	2 CO_2	+	3 H_2O	+	13.16 N_2
1 C_3H_8	+	5 O_2	+	18.8 N_2	=	3 CO_2	+	4 H_2O	+	18.8 N_2
1 C_4H_{10}	+	6.5 O_2	+	24.44 N_2	=	4 CO_2	+	5 H_2O	+	24.44 N_2
1 C_5H_{12}	+	8 O_2	+	30.08 N_2	=	5 CO_2	+	6 H_2O	+	30.08 N_2
1 C_6H_{14}	+	9.5 O_2	+	35.72 N_2	=	6 CO_2	+	7 H_2O	+	35.72 N_2
1 C_7H_{16}	+	11 O_2	+	41.36 N_2	=	7 CO_2	+	8 H_2O	+	41.36 N_2
1 C_8H_{18}	+	12.5 O_2	+	47 N_2	=	8 CO_2	+	9 H_2O	+	47 N_2
1 C_9H_{20}	+	14 O_2	+	52.64 N_2	=	9 CO_2	+	10 H_2O	+	52.64 N_2
1 $C_{10}H_{22}$	+	15.5 O_2	+	58.28 N_2	=	10 CO_2	+	11 H_2O	+	58.28 N_2
1 H_2S	+	1.5 O_2	+	5.64 N_2	=	1 SO_2	+	1 H_2O	+	5.64 N_2

Source: S&P Global Energy.

Table 5

Enthalpies of formation and molecular weights of common compounds

Substance	Chemical formula	Enthalpy of formation (KJ/kmol)	Molecular weight (kg/kmol)
Hydrogen	$H_2(g)$	0	2.016
Methane	$CH_4(g)$	-74553	16.04
Ethane	$C_2H_6(g)$	-83750	30.07
Propane	$C_3H_8(g)$	-104630	44.10
i-Butane	$C_4H_{10}(g)$	-135270	58.12
n-Butane	$C_4H_{10}(g)$	-125820	58.12
i-Pentane	$C_5H_{12}(g)$	-153170	72.15
n-Pentane	$C_5H_{12}(g)$	-146250	72.15
n-Hexane	$C_6H_{14}(l)$	-198640	86.18
n-Heptane	$C_7H_{16}(l)$	-224180	100.21
n-Octane	$C_8H_{18}(l)$	-249730	114.23
n-nonane	$C_9H_{20}(l)$	-274690	128.26
n-decane	$C_{10}H_{22}(l)$	-300560	142.29
Carbon dioxide	$CO_2(g)$	-393520	44.01
Water	$H_2O(g)$	-241834	18.02
Water	$H_2O(l)$	-285830	18.02
Hydrogen sulfide	$H_2S(g)$	-20270	34.1
Sulphur dioxide	$SO_2(g)$	-296680	64.1

Source: https://atct.anl.gov/Thermochemical%20Data/version%201.122v/index.php.

LHV and HHV calculations for common fuels

Table 6

Calculated HHV and LHV for various compounds

Substance	Chemical formula	LHV (MJ/kg)	HHV (MJ/kg)
Hydrogen	$H_2(g)$	120.0	141.8
Methane	$CH_4(g)$	50.0	55.5
Ethane	$C_2H_6(g)$	47.5	51.9
Propane	$C_3H_8(g)$	46.3	50.3
i-Butane	$C_4H_{10}(g)$	45.6	49.3
n-Butane	$C_4H_{10}(g)$	45.7	49.5
i-Pentane	$C_5H_{12}(g)$	45.3	48.9
n-Pentane	$C_5H_{12}(g)$	45.4	49.0
n-Hexane	$C_6H_{14}(l)$	44.7	48.3
n-Heptane	$C_7H_{16}(l)$	44.6	48.1
n-Octane	$C_8H_{18}(l)$	44.4	47.9
n-nonane	$C_9H_{20}(l)$	44.3	47.8
n-decane	$C_{10}H_{22}(l)$	44.2	47.6
Hydrogen sulfide	$H_2S(g)$	15.2	16.5

Source: S&P Global Energy.

LHV and HHV based upon fuel composition

Table 7

Example calculation of rich gas heating value

Composition	% volume	Density (kg/m³)	% mass	HHV (MJ/kg)	LHV (MJ/kg)
C_1	84.3	0.679	68.9	55.5	50.0
C_2	9.9	1.272	15.2	51.9	47.5
C_3	0.5	1.865	1.1	50.3	46.3
iC_4	0.0	2.458	0.0	49.3	45.6
nC_4	0.1	2.458	0.3	49.5	45.7
iC_5	3.1	3.052	11.4	48.9	45.3
H_2	0	0.085	0.0	141.8	120.0
He	0	0.169	0.0	0.0	0.0
N_2	1.7	1.185	2.4	0.0	0.0
CO_2	0.1	1.861	0.2	0.0	0.0
H_2S	0.3	1.442	0.5	16.5	15.2
Total	100.0	0.83	100.0	52.5	47.6

Source: S&P Global Energy.

Crude oil heating values

A correlation between heating values and API gravity of crude oil can be made and data extracted from the Fuel Oil Manual is presented in Table 8. The assumptions are for representative crude oil compositions, discrepancies might surface if using this table for evaluating crudes with much different composition than what would be typical of a fossil crude.

Table 8

Higher and lower heating values of crude oil correlated to API gravity

Crude density		LHV – US standard units			HHV – US standard units			LHV – SI units			HHV – SI units		
Deg API	SG	Btu/lb	Btu/gal	MMBtu/b	Btu/lb	Btu/l	MMBtu/b	MJ/lb	MJ/kg	MJ/b	MJ/lb	MJ/kg	MJ/b
4	1.044	16910	147250	6.18	17930	41268	6.56	17.84	39.33	6525	18.92	41.69	6922
5	1.037	16990	146860	6.17	17980	41079	6.53	17.92	39.52	6508	18.97	41.81	6890
6	1.029	17050	146340	6.15	18030	40894	6.50	17.99	39.66	6485	19.02	41.92	6859
7	1.022	17110	145790	6.12	18090	40734	6.48	18.05	39.80	6460	19.08	42.06	6832
8	1.014	17170	145260	6.10	18150	40576	6.45	18.11	39.94	6437	19.15	42.20	6806
9	1.007	17230	144700	6.08	18210	40420	6.43	18.18	40.08	6412	19.21	42.34	6780
10	1.000	17270	144000	6.05	18260	40245	6.40	18.22	40.17	6381	19.26	42.46	6750
11	0.993	17310	143410	6.02	18310	40072	6.37	18.26	40.26	6355	19.32	42.57	6721
12	0.986	17350	142720	5.99	18360	39901	6.34	18.30	40.35	6324	19.37	42.69	6693
13	0.979	17400	142030	5.97	18410	39733	6.32	18.36	40.47	6294	19.42	42.81	6665
14	0.973	17440	141440	5.94	18450	39546	6.29	18.40	40.56	6268	19.46	42.90	6633
15	0.966	17480	140750	5.91	18500	39382	6.26	18.44	40.66	6237	19.52	43.02	6606
16	0.959	17520	140160	5.89	18550	39221	6.24	18.48	40.75	6211	19.57	43.13	6579
17	0.953	17550	139470	5.86	18600	39062	6.21	18.52	40.82	6180	19.62	43.25	6552
18	0.946	17590	138790	5.83	18650	38905	6.19	18.56	40.91	6150	19.68	43.37	6526
19	0.940	17630	138190	5.80	18700	38750	6.16	18.60	41.01	6124	19.73	43.48	6500
20	0.934	17660	137510	5.78	18740	38577	6.13	18.63	41.08	6093	19.77	43.57	6471
21	0.928	17690	136910	5.75	18780	38406	6.11	18.66	41.14	6067	19.81	43.67	6442
22	0.922	17730	136230	5.72	18820	38237	6.08	18.71	41.24	6037	19.86	43.76	6413
23	0.916	17760	135640	5.70	18860	38070	6.05	18.74	41.31	6011	19.90	43.85	6386

Table 8

Higher and lower heating values of crude oil correlated to API gravity (continued)

Crude density		LHV – US standard units			HHV – US standard units			LHV – SI units			HHV – SI units		
Deg API	SG	Btu/lb	Btu/gal	MMBtu/b	Btu/lb	Btu/l	MMBtu/b	MJ/lb	MJ/kg	MJ/b	MJ/lb	MJ/kg	MJ/b
24	0.910	17800	135040	5.67	18900	37905	6.03	18.78	41.40	5984	19.94	43.95	6358
25	0.904	17830	134350	5.64	18940	37743	6.00	18.81	41.47	5953	19.98	44.04	6331
26	0.898	17860	133760	5.62	18980	37582	5.97	18.84	41.54	5927	20.02	44.13	6304
27	0.893	17890	133170	5.59	19020	37424	5.95	18.87	41.61	5901	20.07	44.23	6277
28	0.887	17920	132580	5.57	19060	37267	5.92	18.91	41.68	5875	20.11	44.32	6251
29	0.882	17950	131890	5.54	19090	37094	5.90	18.94	41.75	5844	20.14	44.39	6222
30	0.876	17980	131300	5.51	19130	36941	5.87	18.97	41.82	5818	20.18	44.48	6196
31	0.871	18000	130710	5.49	19160	36771	5.85	18.99	41.87	5792	20.21	44.55	6168
32	0.865	18030	130120	5.47	19200	36623	5.82	19.02	41.94	5766	20.26	44.64	6143
33	0.860	18050	129530	5.44	19230	36457	5.80	19.04	41.98	5740	20.29	44.71	6115
34	0.855	18080	128940	5.42	19270	36312	5.77	19.07	42.05	5714	20.33	44.81	6091
35	0.850	18110	128350	5.39	19300	36150	5.75	19.11	42.12	5687	20.36	44.88	6064
36	0.845	18130	127560	5.36	19330	35990	5.72	19.13	42.17	5652	20.39	44.95	6037
37	0.840	18150	127160	5.34	19360	35832	5.70	19.15	42.21	5635	20.42	45.02	6010
38	0.835	18180	126570	5.32	19390	35676	5.67	19.18	42.28	5609	20.46	45.09	5984
39	0.830	18200	125980	5.29	19420	35522	5.65	19.20	42.33	5582	20.49	45.16	5958
40	0.825	18230	125390	5.27	19450	35369	5.62	19.23	42.40	5556	20.52	45.23	5933
41	0.820	18250	124800	5.24	19480	35218	5.60	19.25	42.45	5530	20.55	45.30	5907
42	0.816	18280	124310	5.22	19510	35069	5.58	19.29	42.52	5508	20.58	45.37	5882
43	0.811	18300	123720	5.20	19530	34904	5.55	19.31	42.56	5482	20.60	45.41	5854
44	0.806	18320	123120	5.17	19560	34758	5.53	19.33	42.61	5456	20.64	45.48	5830
45	0.802	18340	122530	5.15	19590	34614	5.50	19.35	42.66	5430	20.67	45.55	5806
46	0.785	18466	121617	5.11	19730	34374	5.47	19.48	42.95	5389	20.82	45.88	5765
47	0.779	18499	121001	5.08	19770	34211	5.44	19.52	43.03	5362	20.86	45.97	5738
48	0.773	18532	120384	5.06	19810	34049	5.41	19.55	43.11	5335	20.90	46.07	5711
49	0.768	18565	119768	5.03	19851	33886	5.39	19.59	43.18	5307	20.94	46.16	5684
50	0.762	18598	119152	5.00	19891	33724	5.36	19.62	43.26	5280	20.99	46.25	5656
51	0.756	18631	118536	4.98	19931	33562	5.34	19.66	43.34	5253	21.03	46.35	5629
52	0.750	18664	117920	4.95	19972	33399	5.31	19.69	43.41	5225	21.07	46.44	5602
53	0.744	18697	117303	4.93	20012	33237	5.28	19.73	43.49	5198	21.11	46.53	5575
54	0.738	18730	116687	4.90	20052	33074	5.26	19.76	43.57	5171	21.16	46.63	5548
55	0.732	18763	116071	4.87	20092	32912	5.23	19.80	43.64	5143	21.20	46.72	5520
56	0.726	18796	115455	4.85	20133	32750	5.21	19.83	43.72	5116	21.24	46.82	5493
57	0.720	18830	114839	4.82	20173	32587	5.18	19.87	43.80	5089	21.28	46.91	5466
58	0.714	18863	114222	4.80	20213	32425	5.16	19.90	43.87	5062	21.33	47.00	5439
59	0.709	18896	113606	4.77	20253	32263	5.13	19.94	43.95	5034	21.37	47.10	5411
60	0.703	18929	112990	4.74	20294	32100	5.10	19.97	44.03	5007	21.41	47.19	5384
62	0.691	18995	111758	4.69	20374	31775	5.05	20.04	44.18	4952	21.50	47.38	5330
63	0.685	19028	111141	4.67	20415	31613	5.03	20.08	44.26	4925	21.54	47.47	5302
64	0.679	19061	110525	4.64	20455	31451	5.00	20.11	44.34	4898	21.58	47.56	5275
65	0.673	19094	109909	4.61	20495	31288	4.98	20.15	44.41	4870	21.62	47.66	5248
66	0.667	19127	109293	4.59	20535	31126	4.95	20.18	44.49	4843	21.67	47.75	5221
67	0.661	19160	108677	4.56	20576	30964	4.92	20.22	44.57	4816	21.71	47.85	5193
68	0.655	19193	108060	4.54	20616	30801	4.90	20.25	44.64	4788	21.75	47.94	5166
69	0.650	19226	107444	4.51	20656	30639	4.87	20.29	44.72	4761	21.79	48.03	5139

Correlations relating crude oil energy density as a function of API gravity, API 46-69 is calculated based on correlation.
Source: Schmidt, Paul F., Fuel Oil Manual, Fourth edition (1985).

Barrel of oil equivalent conversion

Barrel of oil equivalent (boe) is a common standardized unit used to compare production volumes with varying produced coproducts (e.g., crude oil, natural gas, natural gas liquids, etc.) of oil and gas. A boe is referenced to an oil with an API gravity of 30 degrees. This seemingly simple conversion is commonly inconsistently reported or converted to. Two key principles can be used as a basis for boe conversion: energy or mass. A mass basis requires knowing the density of the products. The challenge is that for liquids, densities vary with temperature and pressure. Converting based upon energy is therefore recommended. In this case, it is just a ratio of heating values that is used to convert from one barrel to another. In this example, we are using higher heating values to convert, but lower heating values could also be used as long as both the numerator and denominator are used on the same basis.

$$boe_{product} = barrel\,product * \frac{HHV_{product}}{HHV_{API\,30}}$$

Table 9

Some common boe conversion factors

Product	Description	HHV (MJ/m³)	Density (kg/m³)[1]	Conversion factor (multiply by)
API 30 Oil	API 30	38,972	876	1
API 8 Oil	API 8	42,806	1014	1.1
Methane	C_1(g)	37.7	0.679	0.00097
Natural gas	Mix (g)	39.5	0.76	0.0010
Ethane	C_2(l)	18,527	357	0.48
Propane	C_3(l)	25,516	507	0.65
Butane	C_4(l)	28,924	584	0.74
NGL mix	C_3,C_4,C_5(l)	27,670	-	0.71
Pentane	C_5(l)	30,904	631	0.79
Condensate	API 60 (l)[2]	33,864	703	0.87

[1] Liquids at 288K and liquid equilibrium pressure, gases at 101.325kPa and 288K calculated with the ideal gas law.

[2] For example only, assume API gravity of 60. Condensates can range in density.

Source: S&P Global Energy.

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