Worksheet on ancillary emissions of methane and CO2: oil and gas operations

Coal methane in separate worksheet

Background calculations on ancillary emissions of methane and carbon dioxide

Heede, CMS
3-Jul-13

Methane

IPCC Tier 1 methodology

IPCC Guidelines 2006: values for methane emissions from Flaring, Venting, and Fugitives from Natural Gas Production and Oil Production

Intergovernmental Panel on Climate Change (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Volume 2: Energy, Chapter 4: Fugitive Emissions, Geneva; www.ipcc-nggip.iges.or.jp/public/2006gl

Methane from Natural Gas: IPCC Tier 1 emission factors

Table 1

	Fugitives				Venting				Flaring			
	Low	High	Average (or unitary)		Low	High	Average (or unitary)		Low	High	Average (or unitary)	
	kg CH4/m^3	kg CH4/m^3	kg CH4/m^3		kg CH4/m^3	kg CH4/m^3	kg CH4/m^3		kg CH4/m^3	kg CH4/m^3	kg CH4/m^3	
Developed countries	Gas factors are GgCH4/million m^3 of production, which equals kg CH4/m^3											
Production	3.80E-04	2.30E-03	0.001340	72%	na	na	na				7.60E-07	
Processing (default)	1.50E-04	1.03E-03	0.000590	75%							2.00E-06	kg CH4/m^3
Transmission & storage	6.60E-05	4.80E-04	0.000273	76%	4.40E-05	3.20E-04	0.000182	76%			2.50E-05	
Distribution			0.001100	not attributed								
Total developed countries	**5.96E-04**	**3.81E-03**	**0.002203**		**4.40E-05**	**3.20E-04**	**0.000182**		**0.00E+00**	**0.00E+00**	**0.000028**	
Developing countries												
Production	3.80E-04	2.40E-02	0.012190	97%	na	na	na		7.60E-07	1.00E-06	0.000001	14%
Processing (default)	1.50E-04	3.50E-04	0.000250	40%	na				2.00E-06	2.80E-06	0.000002	17%
Transmission & storage	1.66E-04	1.10E-03	0.000633	74%	4.40E-05	7.40E-04	0.000392	89%	2.50E-05	5.80E-05	0.000042	40%
Distribution	1.10E-03	2.50E-03	0.001800	not attributed								
Total developing countries	**6.96E-04**	**2.55E-02**	**0.013073**		**0.000044**	**0.000740**	**0.000392**		**2.78E-05**	**6.18E-05**	**0.0000448**	
Average of Developed and Developing			**0.007638**	kg CH4/m^3			**0.000287**	kg CH4/m^3			**0.000036**	kg CH4/m^3
	Gas combustion C		1.89	kg CO2/m^3	Gas combustion C(		1.89	kg CO2/m^3	Gas combustion CO2		1.89	kg CO2/m^3
	Gas combustion C		0.002	t CO2/m^3	Gas combustion C(		0.002	t CO2/m^3	Gas combustion CO2		0.002	t CO2/m^3
	Conversion		529.94	m^3/t CO2	Conversion		529.94	m^3/t CO2	Conversion		529.94	m^3/t CO2
	Methane rate		**4.048**	**kg CH4/t CO2**	**Methane rate**		**0.152**	**kg CH4/t CO2**	**Methane rate**		**0.019**	**kg CH4/t CO2**
	kg of methane per t CO2 from gas combustion				kg of methane per t CO2 from gas combustion				kg of methane per t CO2 from gas combustion			

Table 2 Summary of methane rates for natural gas

Source	kg CH4/t CO2	g CH4/cf
Fugitives	**4.048**	0.216
Venting	**0.152**	0.008
Flaring	**0.019**	0.001
Total	**4.219**	**0.2254**

Table 3 Combustion factors for fuels

	Combustion EF	Units		Combustion EF	Converted to
Crude oil & NGLs	0.3714	MtCO2/million bbl	tCO2/bbl	2,336.21	kg CO2/m^3
Natural gas	0.0534	MtCO2/Bcf	kgCO2/cf	1.89	kg CO2/m^3

linked to SumOil & SumGas EF worksheets

2.65 tCO2/t of oil

Conversions	Units
35.315	cf/m^3
158.99	L /bbl
1,000.00	L /m^3
6.290	bbl /m^3

Methane

IPCC Tier 1 methodology

IPCC Guidelines 2006: values for methane emissions from Flaring, Venting, and Fugitives from Natural Gas Production and Oil Production

Intergovernmental Panel on Climate Change (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Volume 2: Energy, Chapter 4: Fugitive Emissions, Geneva; www.ipcc-nggip.iges.or.jp/public/2006gl

Methane from Crude Oil: IPCC Tier 1 emission factors

Table 4 Crude oil

	Fugitives				Venting				Flaring			
	Low	High	Average (or unitary)		Low	High	Average (or unitary)		Low	High	Average (or unitary)	
	t CH4/m^3	t CH4/m^3	t CH4/m^3		t CH4/m^3	t CH4/m^3	t CH4/m^3		t CH4/m^3	t CH4/m^3	t CH4/m^3	
Developed countries	Oil factors are GgCH4/10^3 m^3 of production, which equals t CH4/m^3											
Well drilling (flaring and venting)	na	na	na		na	na	0.000033		na	na	na	
Well testing (flaring and venting)	na	na	na		na	na	0.000051		na	na	na	
Well servicing (flaring and venting)	na	na	na		na	na	0.000110		na	na	na	
Production	na	na	0.002200	uncertainty estimates	na	na	0.008700		na	na	0.000021	t CH4/m^3
Refining	0.000003	0.000041	0.000022	88%	na	na	na		na	na	na	
Transport (pipelines)	na	na	0.000005		na	na	na		na	na	na	
Transport (rail and truck)	na	na	0.000025		na	na	na		na	na	na	
Condensate transport	na	na	0.000110		na	na	na		na	na	na	
Distribution	na	na	na		na	na	na		na	na	na	
Total developed countries			**0.002362**				**0.008894**				**0.000021**	
Developing countries												
Well drilling	na	na	na		na	na	na		na	na	na	
Well testing	na	na	na		na	na	na		na	na	na	
Well servicing	na	na	na		na	na	na		na	na	na	t CH4/m^3
Production	0.002200	0.003700	0.002950	25%	0.008700	0.012000	0.010350	16%	0.000021	0.000029	0.000025	16%
Refining	ND	ND	ND		ND	ND	ND		ND	ND	ND	
Oil transport - pipelines	na	na	0.000005		na	na	na		na	na	na	
Transport (rail and truck)	na	na			na	na	0.000025		na	na	na	
Condensate transport	na	na	0.000110		na	na	na		na	na	na	
Distribution	na	na			na	na	na		na	na	na	
Total developing countries	**0.002200**	**0.003700**	**0.003065**	21%	**0.008700**	**0.012000**	**0.010350**	16%	**0.000021**	**0.000029**	**0.000025**	16%
Average of Developed and Developing			0.005428	t CH4/m^3			0.019244	t CH4/m^3			0.000046	t CH4/m^3

Convert to kg	5.43	kg CH4/m^3	Convert to kg	19.24	kg CH4/m^3
Oil combustion C(	2,336.21	kg CO2/m^3	Oil combustion CO	2,336.21	kg CO2/m^3
Oil combustion C(	2.34	t CO2/m^3	Oil combustion CO	2.34	t CO2/m^3
Conversion	0.43	m^3/t CO2	Conversion	0.43	m^3/t CO2
Methane rate	**2.323**	**kg CH4/t CO2**	**Methane rate**	**8.237**	**kg CH4/t CO2**
kg of methane per t CO2 from oil combustion			kg of methane per t CO2 from oil combustion		

Convert to kg	0.05	kg CH4/m^3
Oil combustion CO2	2,336.21	kg CO2/m^3
Oil combustion CO2	2.34	t CO2/m^3
Conversion	0.43	m^3/t CO2
Methane rate	**0.020**	**kg CH4/t CO2**
kg of methane per t CO2 from oil combustion		

Table 5 Summary of methane rates for crude oil

Source	kg CH4/t CO2	kg CH4/bbl
Fugitives	**2.323**	0.863
Venting	**8.237**	3.060
Flaring	**0.020**	0.007
Total	**10.580**	**3.930**

verified

Table 6

Final Oil & Natural Gas methane rates

Table of factors calculated on this worksheet and linked to the entity summary worksheet (SumRanking.xls)

Final Oil & Natural Gas methane rates				Carbon Dioxide: see worksheet "Flaring & Venting"			
Methane							
Crude oil & NGLs	Natural gas	Oil & Gas Prod'n	Percent	Oil Production	Oil Production	Gas Production	Gas Production
kg CH4/t CO2	kg CH4/t CO2	kg CH4/t CO2		kg CO2/t CO2	Percent	kg CO2/t CO2	Percent
EPA values 28-Dec-12							
1.92	9.88						
linked to Table 30 EPA CH4: Oil	linked to Table 32 EPA CH4: Gas						
IPCC values: (Dec12) 10.58	4.22						
linked to Table 5	linked to Table 2						

Summary of Ancillary factors used in SumRanking.xls

Background data on IPCC Tier 1 methane in natural gas and crude oil: methodology and values

IPCC Tier 1 methodology

IPCC Guidelines 2006: values for methane emissions from Flaring, Venting, and Fugitives from Natural Gas Production and Oil Production

Intergovernmental Panel on Climate Change (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Volume 2: Energy, Chapter 4: Fugitive Emissions, Geneva; www.ipcc-nggip.iges.or.jp/public/2006gl

The images below show IPCC Tier 1 factors for natural gas and oil production, developing and developed countries;
Listed above in Tables 1 and 2 are several other methane emission sources for each natural gas and oil. See IPCC 2006, vol 2, chapter 4: Fugitives, for details.

TABLE 4.2.4(CONTINUED)
TIER 1 EMISSION FACTORS FOR FUGITIVE EMISSIONS (INCLUDING VENTING AND FLARING) FROM OIL AND GAS OPERATIONS
IN DEVELOPED COUNTRIES[a,b]

Category	Sub-category[c]	Emission source	IPCC Code	CH_4 Value	CH_4 Uncertainty (% of value)	CO_2[1] Value	CO_2[1] Uncertainty (% of Value)	NMVOC Value	NMVOC Uncertainty (% of value)	N_2O Value	N_2O Uncertainty (% of value)	Units of measure
	Deep-cut Extraction Plants (Straddle Plants)	Fugitives	1.B.2.b.iii.3	1.1E-05	±100%	1.6E-06	±100%	2.7E-05	±100%	NA	NA	Gg per 10^6 m^3 raw gas feed
		Flaring	1.B.2.b.ii	7.2E-08	±25%	1.1E-04	±50%	5.9E-08	±25%	1.2E-08	-10 to +1000%	Gg per 10^6 m^3 raw gas feed
	Default Weighted Total	Fugitives	1.B.2.b.iii.3	1.5E-04 to 10.3E-04	±100%	1.2E-05 to 3.2E-04	±100%	1.4E-04 to 4.7E-04	±100%	NA	NA	Gg per 10^6 m^3 gas production
		Flaring	1.B.2.b.ii	2.0E-06	±25%	3.0E-03	±50%	1.6E-06	±25%	3.3E-08	-10 to +1000%	Gg per 10^6 m^3 gas production
		Raw CO_2 Venting	1.B.2.b.i	NA	N/A	4.0E-02	-10 to +1000%	NA	N/A	NA	N/A	Gg per 10^6 m^3 gas production
Gas Transmission & Storage	Transmission	Fugitives[a,b]	1.B.2.b.iii.4	6.6E-05 to 4.8E-04	±100%	8.8E-07	±100%	7.0E-06	±100%	NA	NA	Gg per 10^6 m^3 of marketable gas
		Venting[a,b]	1.B.2.b.i	4.4E-05 to 3.2E-04	±75%	3.1E-06	±75%	4.6E-06	±75%	NA	NA	Gg per 10^6 m^3 of marketable gas
	Storage	All[b]	1.B.2.b.iii.4	2.5E-05	-20 to +500%	1.1E-07	-20 to +500%	3.6E-07	-20 to +500%	ND	ND	Gg per 10^6 m^3 of marketable gas

Default values, Natural Gas Production, Developed Countries

TABLE 4.2.4(CONTINUED)
TIER 1 EMISSION FACTORS FOR FUGITIVE EMISSIONS (INCLUDING VENTING AND FLARING) FROM OIL AND GAS OPERATIONS
IN DEVELOPED COUNTRIES[a,b]

Category	Sub-category[c]	Emission source	IPCC Code	CH_4 Value	CH_4 Uncertainty (% of value)	CO_2[1] Value	CO_2[1] Uncertainty (% of Value)	NMVOC Value	NMVOC Uncertainty (% of value)	N_2O Value	N_2O Uncertainty (% of value)	Units of measure
	Deep-cut Extraction Plants (Straddle Plants)	Fugitives	1.B.2.b.iii.3	1.1E-05	±100%	1.6E-06	±100%	2.7E-05	±100%	NA	NA	Gg per 10^6 m^3 raw gas feed
		Flaring	1.B.2.b.ii	7.2E-08	±25%	1.1E-04	±50%	5.9E-08	±25%	1.2E-08	-10 to +1000%	Gg per 10^6 m^3 raw gas feed
	Default Weighted Total	Fugitives	1.B.2.b.iii.3	1.5E-04 to 10.3E-04	±100%	1.2E-05 to 3.2E-04	±100%	1.4E-04 to 4.7E-04	±100%	NA	NA	Gg per 10^6 m^3 gas production
		Flaring	1.B.2.b.ii	2.0E-06	±25%	3.0E-03	±50%	1.6E-06	±25%	3.3E-08	-10 to +1000%	Gg per 10^6 m^3 gas production
		Raw CO_2 Venting	1.B.2.b.i	NA	N/A	4.0E-02	-10 to +1000%	NA	N/A	NA	N/A	Gg per 10^6 m^3 gas production
Gas Transmission & Storage	Transmission	Fugitives[a,b]	1.B.2.b.iii.4	6.6E-05 to 4.8E-04	±100%	8.8E-07	±100%	7.0E-06	±100%	NA	NA	Gg per 10^6 m^3 of marketable gas
		Venting[a,b]	1.B.2.b.i	4.4E-05 to 3.2E-04	±75%	3.1E-06	±75%	4.6E-06	±75%	NA	NA	Gg per 10^6 m^3 of marketable gas
	Storage	All[b]	1.B.2.b.iii.4	2.5E-05	-20 to +500%	1.1E-07	-20 to +500%	3.6E-07	-20 to +500%	ND	ND	Gg per 10^6 m^3 of marketable gas

Default values, Natural Gas Production, Developing Countries

TABLE 4.2.4(CONTINUED)
TIER 1 EMISSION FACTORS FOR FUGITIVE EMISSIONS (INCLUDING VENTING AND FLARING) FROM OIL AND GAS OPERATIONS
IN DEVELOPED COUNTRIES[a,b]

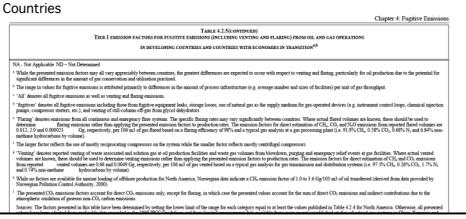
Category	Sub-category[c]	Emission source	IPCC Code	CH_4 Value	CH_4 Uncertainty (% of value)	CO_2[1] Value	CO_2[1] Uncertainty (% of Value)	NMVOC Value	NMVOC Uncertainty (% of value)	N_2O Value	N_2O Uncertainty (% of value)	Units of measure
	Deep-cut Extraction Plants (Straddle Plants)	Fugitives	1.B.2.b.iii.3	1.1E-05	±100%	1.6E-06	±100%	2.7E-05	±100%	NA	NA	Gg per 10^6 m^3 raw gas feed
		Flaring	1.B.2.b.ii	7.2E-08	±25%	1.1E-04	±50%	5.9E-08	±25%	1.2E-08	-10 to +1000%	Gg per 10^6 m^3 raw gas feed
	Default Weighted Total	Fugitives	1.B.2.b.iii.3	1.5E-04 to 10.3E-04	±100%	1.2E-05 to 3.2E-04	±100%	1.4E-04 to 4.7E-04	±100%	NA	NA	Gg per 10^6 m^3 gas production
		Flaring	1.B.2.b.ii	2.0E-06	±25%	3.0E-03	±50%	1.6E-06	±25%	3.3E-08	-10 to +1000%	Gg per 10^6 m^3 gas production
		Raw CO_2 Venting	1.B.2.b.i	NA	N/A	4.0E-02	-10 to +1000%	NA	N/A	NA	N/A	Gg per 10^6 m^3 gas production
Gas Transmission & Storage	Transmission	Fugitives[a,b]	1.B.2.b.iii.4	6.6E-05 to 4.8E-04	±100%	8.8E-07	±100%	7.0E-06	±100%	NA	NA	Gg per 10^6 m^3 of marketable gas
		Venting[a,b]	1.B.2.b.i	4.4E-05 to 3.2E-04	±75%	3.1E-06	±75%	4.6E-06	±75%	NA	NA	Gg per 10^6 m^3 of marketable gas
	Storage	All[b]	1.B.2.b.iii.4	2.5E-05	-20 to +500%	1.1E-07	-20 to +500%	3.6E-07	-20 to +500%	ND	ND	Gg per 10^6 m^3 of marketable gas

Default values, Oil Production, Developed Countries

TABLE 4.2.4(CONTINUED)
TIER 1 EMISSION FACTORS FOR FUGITIVE EMISSIONS (INCLUDING VENTING AND FLARING) FROM OIL AND GAS OPERATIONS
IN DEVELOPED COUNTRIES[a,b]

Category	Sub-category[c]	Emission source	IPCC Code	CH_4 Value	CH_4 Uncertainty (% of value)	CO_2[1] Value	CO_2[1] Uncertainty (% of Value)	NMVOC Value	NMVOC Uncertainty (% of value)	N_2O Value	N_2O Uncertainty (% of value)	Units of measure
	Deep-cut Extraction Plants (Straddle Plants)	Fugitives	1.B.2.b.iii.3	1.1E-05	±100%	1.6E-06	±100%	2.7E-05	±100%	NA	NA	Gg per 10^6 m^3 raw gas feed
		Flaring	1.B.2.b.ii	7.2E-08	±25%	1.1E-04	±50%	5.9E-08	±25%	1.2E-08	-10 to +1000%	Gg per 10^6 m^3 raw gas feed
	Default Weighted Total	Fugitives	1.B.2.b.iii.3	1.5E-04 to 10.3E-04	±100%	1.2E-05 to 3.2E-04	±100%	1.4E-04 to 4.7E-04	±100%	NA	NA	Gg per 10^6 m^3 gas production
		Flaring	1.B.2.b.ii	2.0E-06	±25%	3.0E-03	±50%	1.6E-06	±25%	3.3E-08	-10 to +1000%	Gg per 10^6 m^3 gas production
		Raw CO_2 Venting	1.B.2.b.i	NA	N/A	4.0E-02	-10 to +1000%	NA	N/A	NA	N/A	Gg per 10^6 m^3 gas production
Gas Transmission & Storage	Transmission	Fugitives[a,b]	1.B.2.b.iii.4	6.6E-05 to 4.8E-04	±100%	8.8E-07	±100%	7.0E-06	±100%	NA	NA	Gg per 10^6 m^3 of marketable gas
		Venting[a,b]	1.B.2.b.i	4.4E-05 to 3.2E-04	±75%	3.1E-06	±75%	4.6E-06	±75%	NA	NA	Gg per 10^6 m^3 of marketable gas
	Storage	All[b]	1.B.2.b.iii.4	2.5E-05	-20 to +500%	1.1E-07	-20 to +500%	3.6E-07	-20 to +500%	ND	ND	Gg per 10^6 m^3 of marketable gas

Default values, Oil Production, Developing Countries



Notes to table 4.2.4 page 4.63

Other sources of methane emissions rates, oil and natural gas

no table # 7 - 9

Table 10

	Shell				CMS							CMS
	internal emissions CO2 & methane	Methane	Estimat'd CO2	Crude prod'n	CMS data Shell prod'n	CMS: Shell oil prod emissions	CMS: Shell gas prod emissions	CMS: Oil+Gas prod emissions	Shell methane emissions per oil+ga	Shell methane if attrib to gas prod	Shell CO2 emissions per Oil+Gas	CMS data Shell gas prod'n
	million tonnes CO2e	k tonnes	MtCO2	million tonnes	million bbl	MtCO2	MtCO2	MtCO2	kg CH4/tonne CO2	kg CH4/tonne CO2	kgCO2/tCO2	Bcf
1990				98.94	725	287	135	422				2,351
1991				108.31	794	314	148	462				2,578
1992				107.68	789	312	138	450				2,391
1993			Total less CH4	107.61	789	312	143	455				2,493
1994				113.08	829	328	141	469				2,448
1995				117.34	860	340	146	486				2,532
1996				123.68	907	359	178	536				3,090
1997	95			124.92	916	362	170	532				2,948
1998	92	522	81	125.16	917	363	165	528	0.988	3.160	153.45	2,872
1999	90	456	80	121.39	890	352	168	520	0.876	2.708	154.57	2,927
2000	92	398	84	124.92	916	362	173	536	0.743	2.294	156.14	3,016
2001	93	261	87	120.40	883	349	191	540	0.484	1.369	161.18	3,315
2002	96	196	92	117.47	861	341	195	536	0.366	1.005	171.79	3,389
2003	102	187	97	118.46	868	343	186	529	0.353	1.007	183.27	3,230
2004	101	192	96	112.19	822	325	185	510	0.376	1.038	188.16	3,215
2005	93	173	89	104.22	764	302	173	476	0.364	0.997	187.10	3,016
2006	88	124	85	101.08	741	293	176	469	0.265	0.706	181.32	3,054
2007	82	119	79	94.56	693	274	172	447	0.266	0.690	176.88	2,998
2008	75	126	72	88.19	646	256	180	436	0.289	0.700	165.29	3,128
2009	69	127	66	82.71	606	240	178	418	0.304	0.713	157.93	3,096
2010	75	125	72	84.20	617	244	195	440	0.284	0.640	163.82	3,396
					average for	1997-2003 only	1,248					

Potential emissions per bbl - kg CO2 per bbl
Internal emissions per produced bbl 66.29 kg CO2 per bbl

Shell's Gorgon CCS: 0.2124 tCO2/ tCO2 from gas prodn/LNG con

ExxonMobil

Table 11

XOM 2005 CCR
near-useless reporting: combines CO2 and CH4 into upstream and downstream and chemicals

upstream:	17	tonnes CO2-eq per 100 tonnes throughtput
downstream	21	
chems	44	

another XOM chart shows (2001):

upstream CO2 = ~	44	million tonnes
refining CO2 ~	58	million tonnes
chems CO2 ~	14	million tonnes
"other CO2 and CH	5	million tonnes (not CO2-e??)

XOM Carbon Disclosure Project Rpt 2010, section 12.2

Fuel	360,000,000	GWh
Electricity	35,000,000	GWh
Steam	15,000,000	GWh
	410,000,000	GWh

Scope 3: use of sold products (New Zealand rep requirement)
1.6 MtCO2e

Scope 1+2 of product GHG, 2010 21.8%
see calcs at right

Proved reserves (Dec10), CDP OGP 1.2

Crude oil & NGLs	8,890,000,000	8,890	million BOE
Unconventional liqui	2,783,000,000	2,783	million BOE
Natural gas	13,136,000,000	13,136	million BOE
		24,809	million BOE

Gross scope 1 by value chain segment CDP, OG2.3

Expl, prod, gas processing	61,000,000	tCO2e
Refining	53,000,000	tCO2e

Chevron

Table 12

ChevTex 2003	63.9	million tonnes	(incl 0.9 Mt "grid credits")
	56.871	89%	CO2
	7.029	11%	methane (CO2-eq at 21xCO2)
means:	0.33471429	MtCH4	
upstream	37.0	MtCO2-e	
downstream	23.7	MtCO2-e	
other	3.2	MtCO2-e	
total / of which:	63.9	MtCO2-e	
combustion	39	MtCO2-e	
flaring + venting	16	MtCO2-e	
other	9	MtCO2-e	

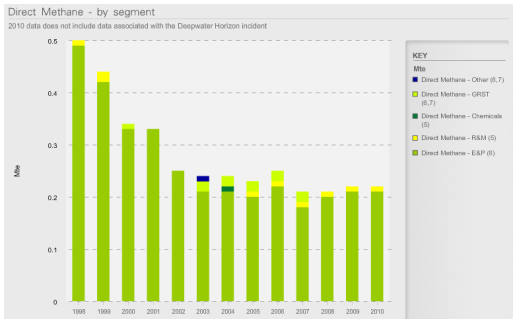
VOCs, 2003 8,555 tonnes VOCs
(p. 16), rate: 25 tonnes per million bbl processed

Chevron 2003

CMS calculations		
CO2 from oil prod	CO2 from gas prod	Oil + Gas Prod'n
MtCO2	MtCO2	MtCO2
284.14	126.39	410.53
If CH4 attributed to Oil & Gas equally		CH4 to Oil + Gas
kgCH4/t CO2	kgCH4/t CO2	kgCH4/t CO2
0.59	1.32	0.82

Table 13 — BP

BP 2010 Rpt	Direct GHG MtCO2e	Indirect GHG million tonnes	Total GHG million tonnes	GHG Rate tCO2e/k boe	Refining GHG intensity tCO2-e/kb/d uEDC	Chemicals intensity tCO2e/kte
1998	84.80	11.67	96.47			
1999	82.81	10.21	93.02	E & P		
2000	83.70	9.66	93.36			
2001	80.50	10.12	90.62	24.9	1,029	528
2002	82.38	11.37	93.75	22.9	977	511
2003	83.43	10.40	93.83	22.2	1,002	509
2004	81.74	9.86	91.60	23.6	944	483
2005	78.03	13.78	91.81			
2006	64.40	10.12	74.52			
2007	63.46	10.67	74.13			
2008	61.40	9.23	70.63			
2009	65.03	9.59	74.62			
2010	64.92	10.00	74.92			
	75.12	10.51	85.64			



Direct GHG by segment, bp.com, HSE Charting tool

Table 14 — BP

BP 2010 Rpt	Direct CO2 MtCO2	Direct CH4 MtCH4	Direct CH4 MtCO2e	Total Direct MtCO2e	Indirect CO2 MtCO2	Total GHG MtCO2e	Total GHG million tonnes	GHG Rate tCO2-e/k boe	Refining GHG intensity tCO2-e/kb/d uEDC	Chemicals intensity tCO2e/kte
1998	84.81	0.50	10.50	95.30	na	95.30				
1999	82.81	0.44	9.24	92.05	na	92.05				
2000	76.55	0.34	7.14	90.84	na	90.84				
2001	73.42	0.33	6.93	87.43	10.10	97.53	178.2	24.9	1,029	528
2002	76.70	0.25	5.25	87.63	11.40	99.03	181.2	22.9	977	511
2003	78.49	0.24	5.04	88.47	10.40	98.87	182.6	22.2	1,002	509
2004	76.84	0.24	5.04	86.78	9.90	96.68	178.8	23.6	944	483
2005	73.24	0.23	4.83	82.86	13.90	96.76	175.1			
2006	59.27	0.25	5.25	69.65						
2007	59.17	0.21	4.41	67.87						
2008	57.04	0.21	4.41	65.81						
2009	60.41	0.22	4.62	69.65						
2010	60.23	0.22	4.62	69.54						
average	70.69	0.28	5.94	81.07	11.14	95.88				

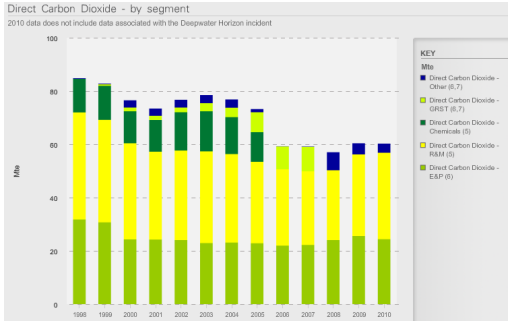


Table 15 — BP

CMS estimate of *product emissions*

	Oil prod'n million bbl/yr	Gas prod'n Bcf/yr	Oil + Gas million BOE/yr	Oil + Gas million tonnes/yr	BP product emissions: Oil 0.3714 MtCO2/million bbl Million tonnes CO2	BP product emissions: Gas 0.0534 MtCO2/Bcf MtCO2	BP product emissions: O+G Est by CMS MtCO2	BP internal CO2 emissions MtCO2	Internal CO2 as percent of product emissions CO2 only	BP internal CH4 emissions MtCO2-eq	Internal CH4 as percent of product emissions CH4 as CO2-eq	BP internal methane emissions *rate (oil+gas)* kg CH4/tonne CO2	BP internal CO2 emissions *rate (oil+gas)* kg CO2/tCO2
1998	704	2,786	1,184	162	261	149	410	85	20.7%	10.50	2.559%	1.218	206.65
1999	705	2,214	1,087	148	262	118	380	83	21.8%	9.24	2.431%	1.157	217.83
2000	737	2,779	1,216	166	274	149	422	84	19.8%	7.14	1.691%	0.805	198.23
2001	774	3,153	1,318	180	287	168	456	91	19.9%	6.93	1.520%	0.724	198.70
2002	924	3,180	1,472	201	343	170	513	94	18.3%	5.25	1.023%	0.487	182.76
2003	935	3,146	1,478	202	347	168	515	94	18.2%	5.04	0.978%	0.466	182.04
2004	903	3,106	1,439	196	336	166	501	92	18.3%	5.04	1.005%	0.479	182.74
2005	935	3,077	1,466	200	347	164	512	92	18.0%	4.83	0.944%	0.449	179.64

Table 16 — BP data global data

	World Oil prod Mtoil	World Gas prod MtOE	World Gas&Oil MtOE	O&GP MtOE
2001	3,594	2,243	5,837	
2002	3,572	2,279	5,851	
2003	3,706	2,361	6,067	2,478
2004	3,865	2,433	6,299	40.85%
2005	3,895	2,487	6,382	of world

Oil 2003 Billion Bbl	Gas 2003 Tcf
27.16	92.55
1 t = 7.33 bbl	1 Mt = 39.2 Bcf

OGP — International Association of Oil and Gas Producers

CO2 Total (MtCO2)	CO2 rate Rate (t/kt)	methane MtCH4	methane MtCO2-eq	methane rate tCH4/kt	methane rate tCO2-eq/t	CO2 + CH4 rate tCO2-eq/t
304.9	126.5	3.0	63.3	1.2520	26.3	152.8

Total assoc prod (Mt) 2,409		Production Mt	Product emissions MtCO2	O&GP CO2 of prod, percent	O&GP methane of prod, percent	O&GP CO2+CH4 of prod, percent
	Percent					
Oil percent (BP)	61.1%	1,471	-	9.31%	1.93%	11.24%
Gas percent (BP	38.9%	938	2,001	5.93%	1.23%	7.16%
Sum	100.0%	2,409	2,001	15.24%	3.17%	18.40%

Appendix shows methane by activity: flared 0.77 Mt, vented 0.81 Mt, Process 0.35 Mt, unspecified 0.76 Mt, Total 2.76 Mt.
Methane by activity: Vented 41 percent, flared 38 percent, process 18 percent, other 3 percent (excl of unspecified).

Note: O&GP data is based on 35 respondent-members whose emissions monitoring quality and comprehensiveness is undefined.
No protocol is discussed
NO mention of oil:gas split in O&GP data

Table 17	OGP				OGP's Oil+Gas production	OGP's Oil+Gas *Emissions*	CMS: emissions rates per tonne of *product emissions*			
	Methane	Methane	Carbon Dioxide	CO2 + Methane			Methane	Methane	Carbon Dioxide	CO2 + Methane
	kg CH4/tonne	kg CO2-eq/t	kg CO2/tonne	kg CO2-eq/tonne	million tonnes	MtCO2	kg CH4/t CO2	kg CO2-eq/t CO2	kg CO2/t CO2	kg CO2-eq/t CO2
Africa	2.03	42.6	332.3	374.9	327	898	0.74	15.52	120.98	136.51
Asia/Aus	2.79	58.6	128.6	187.2	270	742	1.02	21.33	46.83	68.16
Europe	0.24	5.0	64.2	69.2	560	1,538	0.09	1.83	23.36	25.20
FSU	1.79	37.6	103.0	140.6	125	343	0.65	13.69	37.49	51.17
Middle East	0.47	9.9	81.5	91.4	207	569	0.17	3.59	29.67	33.26
North America	1.16	24.4	105.8	130.2	676	1,857	0.42	8.87	38.53	47.40
South America	1.47	30.9	99.1	130.0	243	667	0.54	11.24	36.08	47.32
Global	**1.25**	**26.29**	**126.5**	**152.8**	2409	6,614	0.46	9.57	46.06	55.64

OGP: "Over 150 billion cubic metres of natural gas are currently flared annually. In 2004, this was equivalent to 30% of EU gas consumption, 25% of US gas consumption, or 75% of Russia's gas exports."
Home page: "OGP members produce more than half the world's oil and about one third of its gas"

Table 18	OGP estimated share of oil:gas		
	1/2 of oil (5y)	1/3 of gas (5y)	Sum Oil+Gas
	million tonnes	million tonnes	million tonnes
	1,863	787	2,650
Percent	**70.3%**	**29.7%**	
	MtCO2/million bb	MtCO2/B**cf**	
	0.3714	0.0534	

Emissions from product combustion	
Oil	Gas
tonne CO2/tonne	onne CO2/tonne gas
2.72	2.80

	OGP's Oil+Gas *production*	OGP's Oil+Gas *Emissions*	Percent of total	
	million tonnes	MtCO2	Percent	
	2,409			
of which, oil:	1,694	4,611	69.7%	Oil
of which, gas	715	2,005	30.3%	Gas
Total	2,409	6,617	100%	
Average per tonne of production		**2.747**	**tonne CO2/tonne**	
	OGP survey data only			

OGP also surveyed energy consumption per tonne of production: 1.40 GJ/t in 2005 (up from 1.35 in 2004 and 1.22 in 2003).
Energy produced on site -- chiefly natural gas -- accounts for 66 percent of energy consumption (plus 8 percent puchased energy and 28 percent "unspecified").

Table 19 EIA (2004) *Documentation for Emissions of Greenhouse Gases in the U.S.:* pp. 67-fwd gives methane venting and fugitive emissions factors on a device and activity basis, but no overall emission rates.

Most important Oil Industry methane sources (USA), 2002			
	Bcf CH4/yr	million tonnes CH4	
Oil tanks	21.89		
Pneumatic devices, high-bleed	17.07		vs
Pneumatic devices, low-bleed	3.17		EIA (2002)
Chemical injection pumps	2.48		million tonnes CH4
Total vented methane	46.33	0.8923158	1.02

Most important Gas Industry methane sources (USA), 2002		
	Bcf CH4/yr	million tonnes CH4
Pneumatic device vents	37.98	
Kimray pumps	11.95	
Well clean ups	7.52	
Dehydrator vents	3.73	
Chemical injection pumps	2.04	
Total emitted methane	347.87	6.70

Table 20 Compare Kirchgessner et al (see below) — 1992

Total methane emissions, US gas industry:			Kirchgessner et al (1997)		
	314	Bcf CH4/yr +/- 105 Bcf	6.04	Tg CH4	Kirchgessner et al (~1997) "Estimate of Methane Emissions from the U.S. Natural Gas Industry,"
	6.040	million tonnes (Tg) CH4 +/- 2.01 Tg	358.7	U.S. dry gas prod'n 1994 Mt	summarizes estimates of methane loss rates ranging from 1 to 10 percent.
	18,821	U.S. gas prod'n 1994 Bcf	16.84	kgCH4/t (gas)	Kirchgessner also estimate methane emissions by industry segment: Fugitive emissions 62.1 percent,
			6.006	**kgCH4/tCO2 (gas)**	Vented emissions 30.0 percent, and Combusted emissions 7.9 percent. (Table 4)

Table 21

Total U.S. oil industry emissions, ICF 1999	60.70	Bcf CH4/yr =	ICF US oil industry CH4 emissions		
			1.16	Tg CH4	
ICF: emissions technically reducible (six measures)	43.70	Bcf CH4/yr	311.3	oil prod'n 1998 Mt	
ICF: emissions economically reducible (six measures)	13.70	Bcf CH4/yr	3.716	kgCH4/t (oil)	
			1.403	**kgCH4/tCO2 (oil)**	

calculated by dividing CH 4 emissions per tonne of oil by the CMS oil combustion factor of 2.78 tCO2/to of oil

Table 22 American Petroleum Institute industry examples

Oil & Gas facilites	Oil throughput	Gas throughput	Oil throughput	Gas throughput	Oil + Gas	Product emissions (MtCO2)			Carbon dioxide & methane emissions rate (percent)			
	million bbl /yr	Bcf /yr	Mt /yr	Mt /yr	Mt /yr	Oil (MtCO2)	Gas (MtCO2)	Oil + Gas (MtCO2)	CO2: Oil sector	CO2: Gas sector	CH4: Oil sector	CH4: Gas sector
1 Onshore Oil Field with High CO2 Content	2.23	10.95	0.304	0.209	0.513	0.959	0.596	1.555	4.39%		5.79%	
2 Offshore Oil & Gas Production Platform	67.89	4.38	9.262	0.083	9.345	29.188	0.238	29.427	0.09%		4.33%	
3 Natural Gas Processing Plant	-	292.00	-	5.565	5.565		15.898	15.898		5.02%		0.27%
4 Refinery	91.25		12.449		12.449	39.231		39.231	12.69%		0.03%	
			At 7.33 bbl /tonne.		At 52.47 Bcf/Mt							

	Process emissions				Methane emissions rate			Carbon dioxide emission rate		
	methane	methane	carbon dioxide	Sum CH4+CO2	Oil sector	Gas sector	Oil+Gas	Oil sector	Gas sector	Oil+Gas
	tonnes CH4	tonnes CO2-eq	tonnes CO2	tonnes CO2-eq	kg CH4/tonne	kg CH4/tonne	kg CH4/tonne	kg CO2/tonne	kg CO2/tonne	kg CO2/tonne
1 Onshore Oil Field with High CO2 Content	2,643	55,503	42,100	97,603	8.69	na: Oil field		138.4	na: Oil field	
2 Offshore Oil & Gas Production Platform	60,179	1,263,759	8,823	1,272,582	6.50		6.44	0.95		0.94
3 Natural Gas Processing Plant	2,039	42,819	798,424	841,243	na: gas processing	0.37		na: gas processing	143.5	
4 Refinery	518	10,878	4,978,652	4,989,530	0.04			399.9		

U.S. Energy Information Administration

Table 23 US methane emissions rates, Oil & Gas Industry

		Oil production	Oil production	Gas production	Gas production	Oil+Gas prod'n	Methane emissions: Oil sector	Methane emissions: Gas sector	Methane emissions: Oil+Gas	Methane emissions rate: Oil sector	Methane emissions rate: Gas sector	Methane emissions rate: Oil+Gas	Methane emissions rate: Oil sector	Methane emissions rate: Gas sector	AER Table 5.1 Field production Crude + NG
		million bbl	million tonnes	Bcf	million tonnes	million tonnes	MtCH4	MtCH4	MtCH4	kg CH4/tonne	kg CH4/tonne	kg CH4/tonne	Percent	Percent	thousand bbl /day
1	1998	2,282	311.3	19,024	362.6	673.9	1.11	6.26	7.37	3.57	17.27	10.94	0.357%	1.727%	8,011
2	1999	2,147	292.9	18,832	358.9	651.8	1.04	6.27	7.31	3.55	17.47	11.22	0.355%	1.747%	7,731
3	2000	2,125	289.9	19,182	365.6	655.5	1.03	6.57	7.60	3.55	17.97	11.59	0.355%	1.797%	7,733
4	2001	2,118	288.9	19,616	373.9	662.7	1.03	6.39	7.42	3.57	17.09	11.20	0.357%	1.709%	7,670
5	2002	2,097	286.1	18,928	360.7	646.8	1.02	6.70	7.72	3.57	18.57	11.93	0.357%	1.857%	7,625
6	2003	2,073	282.9	19,099	364.0	646.9	1.01	6.66	7.67	3.57	18.30	11.86	0.357%	1.830%	7,400
7	2004	1,978	269.8	18,591	354.3	624.2	0.97	6.73	7.70	3.59	18.99	12.34	0.359%	1.899%	7,228
8	2005	1,890	257.9	18,051	344.0	601.9	0.92	6.70	7.62	3.57	19.48	12.66	0.357%	1.948%	6,895
9	2006	1,862	254.1	18,504	352.7	606.7	0.91	7.00	7.92	3.59	19.86	13.05	0.359%	1.986%	6,841
10	2007	1,848	252.2	19,266	367.2	619.4	0.90	7.26	8.16	3.58	19.76	13.17	0.358%	1.976%	6,847
11	2008	1,807	246.5	20,159	384.2	630.7	0.88	7.37	8.25	3.59	19.18	13.08	0.359%	1.918%	6,734
12	2009	1,957	266.9	20,580	392.2	659.2	0.94	7.32	8.26	3.52	18.66	12.53	0.352%	1.866%	7,270
13	2010	2,012	274.5	21,577	411.2	685.7									7,513
	average	2,015	274.9	19,339	369	643	0.98	6.77	7.75	3.57	18.55	12.13	0.329%	1.71%	

At 7.33 bbl /t — At 0.0191 Mt/Bcf

EIA uses AR4 at 25xCO2 for methane

Note: CMS lists CH4 emissions from the entire U.S. Natural Gas System, which totaled 6.73 million tonnes in 2004.
However, gas production emits 1.89 MtCH4, Processing 0.65 MtCH4, Transmission & Storage 2.34 MtCH4, and Distribution 1.85 MtCH4.
EIA (2006) *Emissions of Greenhouse Gases in the U.S., 2005*, now uses methane GWP of 23xCO2.

Miscellaneous estimates of methane emissions from oil and gas production

Table 24

CMS added 15Sep07 (for NM gas WELC)

Natural Gas production

Year	Source		Percent loss	kg CH4/tonne	kg CH4/t CO2
1990	Canadian Gas Associ	Canada	0.28%	2.75	0.98
1989	Alphatania Group	international	0.16%	1.63	0.58
1989	Arthur D. Little	global	0.53%	5.30	1.89
1990	Okken	Germany	0.50%	5.00	1.78
1993	US EPA	USA 1990	0.46%	4.60	1.64
1993	US EPA	USA 2000	0.42%	4.20	1.50
1995	Gas Research Institut	USA	0.75%	7.50	2.68
1996	Radian International	USA 1992	0.82%	8.20	2.92
1999	US EPA	USA	0.79%	7.90	2.82
Average of estimates cited in Delucchi			**0.52%**	**5.23**	**1.87**
1982	Shepard	global 1975	1.60%	16.00	5.71
1984	Darmstadter	global	0.64%	6.40	2.28
1987	Crutzen	global	2.56%	25.60	9.13
1988	Cicerone & Oremland	global	2.46%	24.60	8.77
1986	Barns & Edmonds	global	1.28%	12.80	4.57
Average of estimates cited in Kirchgessner			**1.71%**	**17.08**	**6.09**

Natural Gas

	Flaring CO2	Gas Prod'n CO2	Total Gas Prod CO2	Methane	Methane	Tot Gas CO2+CH4	Percent CH4
	Million tonnes CO2	Million tonnes CO2	Million tonnes CO2	Million tonnes CH4	Mt CO2-e	Mt CO2-e	of total
US, 2005	5.9	17.3	23.20	6.7	140.7	163.90	85.8%
					21xCO2		

	US Gas prod'n	US Gas prod'n	Gas CO2 Rate	Gas Methane Rate	Gas Methane Rate	Tot Gas CO2+CH4	Percent CH4
	Bcf	Million tonnes	t CO2/Bcf	t CH4/Bcf	t CO2-e/Bcf	t CO2-e/Bcf	of total
US, 2005	18,215	347.15	1,274	368	8,460	9,734	86.9%

Crude Oil

	Flaring CO2			Methane	Methane
	Million tonnes CO2			Million tonnes CH4	Mt CO2-e
US, 2005	no data			0.92	21.16

	US oil production	US oil production	US oil consumption	Gas Methane Rate	Gas Methane Rate
	million bbl per day	million bbl per yr	million bbl per yr	t CH4/million bbl	t CO2-e/million bbl
US, 2005	5.121	1,869	7,539	492	11,321

Table 25 World Bank Flaring estimates

	Billion cubic m/yr	Bcf /yr	MtCO2
Global Flaring	135.0	4,768	255
Natural Gas prod'n 2004		-	-
Ratio of flared to produced gas		#DIV/0!	#DIV/0!

1 m^3 = 35.315 cubic feet

673 kg per m^3
1 kg per m^3 = 0.0624 lb/cf

Table 26 Conversion tables

Natural Gas & Oil / Production Emissions

1 million tonnes of natural gas =	52.47	Bcf
1 Bcf =	0.01906	Mt of production
1 Bcf =	0.0534	MtCO2 (Step 8)
1 Mt of gas production =	2.8036	MtCO2 emitted
1 MtCO2 =	0.3567	Mt gas prod
1 tonne oil =	3.1514	t CO2 emitted
t CO2 emitted =	0.3173	tonne oil

Methane

	23.5516	cf CH4 = 1 lb
1 Bcf CH4 =	19,260	tonnes
1 Mt CH4 =	51.921	Bcf CH4

1 t = 7.33 bbl | 1 Mt Oil equiv = 39.2 Bcf of natural gas

EPA Methane Converter

1 cf CH4 =	0.04246	lb CH4
1 lb =	23.552	cf
1 ton =	47,103	cf
1 tonne =	51,922	cf
1 tonne =	1,470	m^3
1 Bcf CH4 =	19,260	tonnes CH4

Natural gas, EPA AP42 (1985)

1 lb =	23.80	cf
1 ton =	47,600	cf
1 tonne =	52,469	cf
1 Bcf =	19,059	t
1 Bcf =	0.019	Mt

Table 27

Ancillary emissions of Methane and Carbon Dioxide in Oil & Gas Operations

		Methane					Carbon Dioxide		
		Oil & Gas sector	emissions per tonne of prod'n	Oil sector specific data	Gas sector specific data	Oil&Gas Combine	Oil sector specific data	Gas sector CH4 from flaring	Oil&Gas Combined General or combined
		kg CH4/t CO2	kg CH4/tonne	kg CH4/t CO2	kg CH4/t CO2	kg CH4/t CO2	kg CO2/t CO2	kg CO2/t CO2	kg CO2-eq/t CO2
OGP 2003 regional	Africa	0.7391	2.0300			0.7391	1		120.98
OGP 2003 regional	Asia/Aus	1.0158	2.7900			1.0158	2		46.83
OGP 2003 regional	Europe	0.0874	0.2400			0.0874	3		23.36
OGP 2003 regional	FSU	0.6517	1.7900			0.6517	4		37.49
OGP 2003 regional	Middle East	0.1711	0.4700			0.1711	5		29.67
OGP 2003 regional	North America	0.4223	1.1600			0.4223	6		38.53
OGP 2003 regional	South America	0.5352	1.4700			0.5352	7		36.08
OGP estimate, 2003	Global average	0.4558	1.2520			0.4558	8		46.06
Chevron, 2003						0.8153	9		
BP emissions data, 1998		1.2185	3.4161			1.2185	10		206.65
BP emissions data, 2004		0.4786	1.3418			0.4786	11		179.64
Shell emissions rates, 1998		0.9885	2.7713			0.9885	12		153.45
Shell emissions rates, 2004		0.3533	0.9906			0.3533	13		183.27
US oil industry, 1998		1.2718	3.5656	1.2718			14		
US oil industry, 2005		1.2726	3.5678	1.2726			15		
US gas industry, 1998		6.1582	17.2655		6.1582		16		
US gas industry, 2005		6.9464	19.4751		6.9464		17		
ICF Consulting, U.S. Oil Industry				1.4032			18		
Kirchgessner et al, U.S. Gas industry					6.0059		19		
CDIAC, CH4 from flaring, 1880		-	*CDIAC attrib to c*	-			20		
CDIAC, CH4 from flaring, 1920		0.2107	*CDIAC attrib to c*	0.2107			21		
CDIAC, CH4 from flaring, 1960		3.9290	*CDIAC attrib to c*	3.9290			22		
CDIAC, CH4 from flaring, 1980		12.1383	*CDIAC attrib to c*	12.1383			23		
CDIAC, CH4 from flaring, 2000		18.3015	*CDIAC attrib to c*	18.3015			24		
CDIAC, CH4 from oil & gas 1860-199		0.0860	*CDIAC attrib to oil*		0.0860		25		
API example: onshore oil & gas field				2.7567			26		43.91
API example: offshore oil & gas platform				2.0618			27		
API example: natural gas processing			*(not included)*		*1.0272*		28		
API example: oil refinery			*(not included)*	*0.0132*			29		126.90
Delucchi, average of 9 estimates			5.2306		1.8656		30		
Kirchgessner, average of 5 estimates			17.0800		6.0921		31		
World Bank flaring: low							32		
World Bank flaring: high							33		
Robinson									
EIA (2011) US Inventory 2009									
Average		**2.6105**		**4.3345**	**4.5257**	**0.6102**		**-**	**90.9175**
				previous oil CH4 factor	previous natgas CH4 factor				

Compare Stern & Kaufmann (1998)

	1994 Tg CH4	
Gas flaring (Stern & Kaufmann)	15.20	TgCH4
Gas supply (Stern & Kaufmann)	17.97	TgCH4
	33.17	TgCH4

World oil & NGL emissions, 1994 (CDIAC	6,905	MtCO2
World natural gas emissions, 1994 (CDI	-	MtCO2

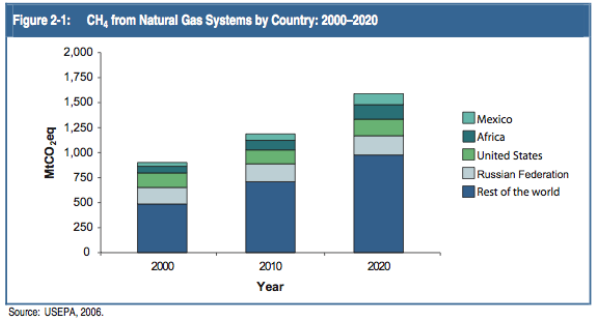
Estimated oil-methane emissions (EPA,	13.2811	TgCH4
Estimated natgas-methane emissions	-	TgCH4
	13.2811	TgCH4

This study exceeds S & K by: **-59.96%**

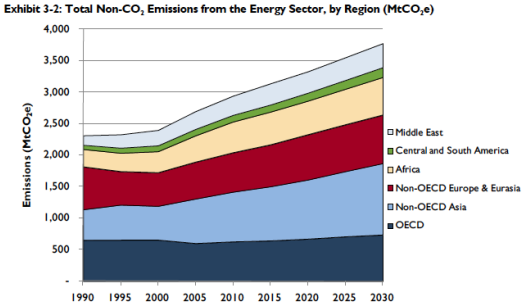
US EPA global methane emissions from coal mining, oil systems, and natural gas systems

US EPA (2006) Global Mitigation of Non-CO2 Greenhouse Gases, Jun06.
www.epa.gov/climatechange/economics/downloads/GlobalMitigationFullReport.pdf

Natural Gas



Source: USEPA, 2006.



US EPA (2011) Draft Global Anthropogenic Non-CO2 Greenhouse Gas Emissions: 1990-2030, Offc Atm Programs, Aug11, 182 pp.
www.epa.gov/nonco2/econ-inv/international.html

Methane Emissions 1990, 1995, 2000, in MtCO2e

Table 2-7: Baseline Emissions for Natural Gas Systems for Selected Countries: 1990–2000 ($MtCO_2eq$)

Country	1990	1995	2000
Russian Federation	334.3	240.6	165.3
United States	143.9	148.0	145.7
Iran	19.4	29.1	34.6
Mexico	22.7	25.3	37.4
Ukraine	78.3	81.8	86.9
Turkmenistan	19.5	16.7	24.3
Nigeria	12.5	17.6	37.8
Venezuela	29.8	34.8	37.7
Turkey	19.9	28.5	38.7
India	8.0	12.5	15.8
United Arab Emirates	18.9	26.7	33.2
Uzbekistan	27.2	30.3	34.8
Indonesia	31.3	41.4	42.1
Canada	25.4	34.3	37.3
Argentina	8.0	10.9	14.9
Rest of the world	**132.0**	**145.3**	**186.0**
World Total	**931.0**	**923.8**	**972.4**

Source: USEPA, 2006.

US EPA (2006) Global Mitigation of Non-CO2 Greenhouse Gases, Jun06, page II-21.

Projected Methane Emissions 1990, 1995, 2000, in MtCO2e

Table 2-8: Projected Baseline Emissions for Natural Gas Systems for Selected Countries: 2005–2020 ($MtCO_2eq$)

Country	2005	2010	2015	2020
Russian Federation	171.9	178.6	185.8	193.1
United States	124.3	138.6	151.0	164.8
Iran	56.8	74.0	96.4	125.3
Mexico	49.5	64.0	82.6	111.4
Ukraine	90.4	93.9	97.7	101.5
Turkmenistan	46.2	72.1	83.2	93.9
Nigeria	49.1	59.2	73.3	89.4
Venezuela	45.2	50.7	63.0	84.8
Turkey	50.2	56.6	62.9	75.5
India	25.8	35.7	49.5	61.4
United Arab Emirates	38.7	47.4	52.8	59.7
Uzbekistan	39.6	44.3	45.4	46.8
Indonesia	46.8	48.0	46.3	45.2
Canada	37.3	38.2	39.8	41.1
Argentina	14.9	16.7	20.9	28.1
Rest of the world	**213.8**	**253.4**	**313.0**	**373.8**
World Total	**1,100.4**	**1,271.5**	**1,463.7**	**1,695.8**

Source: USEPA, 2006.

US EPA (2006) Global Mitigation of Non-CO2 Greenhouse Gases, Jun06, page II-23.

Table 2-6: IPCC Estimated Emissions Factors from Natural Gas by Region

	Emissions Factors by Industry Segment (kg/petajoule)	
Country/Region	**Production**	**Consumption**
Eastern Europe/FSU[a]	392,800	527,900
Other oil-exporting countries[b]	67,795	228,310
United States and Canada	71,905	88,135
Western Europe[c]	20,900	84,500
Rest of the world[d]	67,795	228,310

Source: IPCC, 1996. Adapted from Reference Manual Tables 1-60, 1-61, 1-62, 1-63, and 1-64.
FSU = Former Soviet Union
[a] Includes Albania, Bulgaria, Czech and Slovak Republics, Hungary, Poland, Romania, and the former Yugoslavia.
[b] Includes Algeria, Nigeria, Venezuela, Indonesia, Iran, Iraq, Kuwait, Saudi Arabia, United Arab Emirates, Ecuador, and Mexico.
[c] Includes Austria, Belgium, Denmark, Faroe Islands, Finland, France, Germany, Gibraltar, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom.
[d] Includes Asia, Africa, Middle East, Oceania, and Latin America.

US EPA (2006) Global Mitigation of Non-CO2 Greenhouse Gases, Jun06, page II-21.

Table 28 — Methane from Natural Gas Systems & calculation of CH4 emission rates

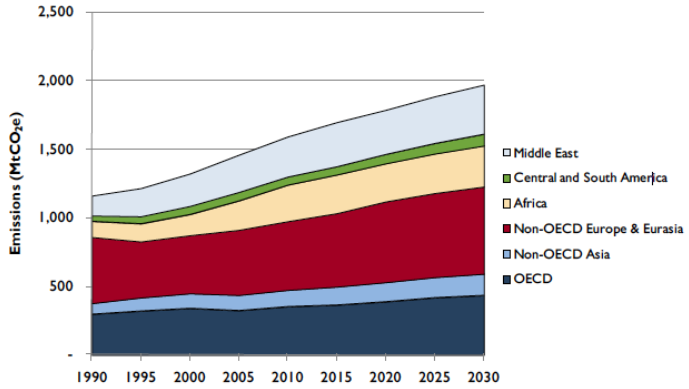
	World gas prod'n	NatGas CO2		NatGas CH4	NatGas CH4	CH4 rate	CH4 rate
	Tcf	MtCO2		MtCO2e	MtCH4	tCH4/Bcf	kg CH4/t CO2
	Table 2-4 and 2-5	CMS		Table 2-7 & 2-8	SAR 21xCO2		
1980	53.35	3,069					
1990	73.57	4,232		931.00	44.33	602.60	10.48
1995	77.96	4,484		923.80	43.99	564.27	9.81
2000	88.29	5,079		972.40	46.30	524.46	9.12
2005	99.79	5,740		1,100.40	52.40	525.09	9.13
2010	105.50	6,069		1,271.50	60.55	573.91	9.98
2015	118.50	6,816		1,463.70	69.70	588.19	10.23
2020	134.50	7,737		1,695.80	80.75	600.39	10.44
2025	151.00	8,686					
	World gas consumption	Based on CMS EF					
	Table 2-5	MtCO2/Bcf				**Average**	**9.88**
	~5 percent higher	0.0575					
1990-2020 totals	**698**	**40,156**		**8,359**			
				Weighted average of 1990 to 2020		**56.86**	**568.42**	**9.91**

Petroleum

US EPA global methane emissions from coal mining, oil systems, and natural gas systems

US EPA (2006) Global Mitigation of Non-CO2 Greenhouse Gases, Jun06.
www.epa.gov/climatechange/economics/downloads/GlobalMitigationFullReport.pdf

Exhibit 3-3: CH_4 Emissions from Natural Gas and Oil Systems 1990 – 2030 ($MtCO_2e$)



EPA (2011) page 3-4.

Table 29	Global methane from Oil & NGL Systems & calculation of CH4 emission rates						
	World oil prod'n	World oil prod'n	Oil CO2	Oil prodn CH4	Oil prodn CH4	CH4 rate	CH4 rate
	million bbl per day	million bbl	MtCO2	MtCO2e	MtCH4	tCH4/million bbl	kg CH4/t CO2
	Table 3-1 & 3-2		CMS	Table 3-5 & 3-6	SAR 21xCO2		
1980	EIA data 1990-2005		-				
1990	65.50	23,906	8,879	62.80	2.99	125.09	0.337
1995	68.85	25,131	9,334	53.50	2.55	101.38	0.273
2000	75.93	27,714	10,294	57.40	2.73	98.62	0.266
2005	82.50	30,113	11,185	64.70	3.08	102.31	0.275
2010	94.30	34,420	12,784	82.90	3.95	114.69	0.309
2015	102.90	37,559	13,950	106.10	5.05	134.52	0.362
2020	110.70	40,406	15,008	131.80	6.28	155.33	0.418
2025	118.90	43,399	16,119				
includes unconventional oil			Based on CMS EF			Average	0.320
~3-5% pa			MtCO2/million bbl				
2010 remains forecast; actual was 84.564			0.3714				
			linked to SumOil.xls				
1990-2020 totals		219,248	81,435	559			
			Weighted average of 1990 to 2020		3.80	118.85	0.327

This calculation thus accounts for CH4 per marketed bbl, not just produced bbl. alternative source
CMS note: This calculates a global average CH4 emission rate; note that Mexico is ~half of global oil CH4.

Table 3-4: IPCC Emissions Factors for Petroleum Systems in Select Regions

	Petroleum System Industry Segments (kg/petajoule)				
	Production				
Region	Fugitive Emissions	Venting and Flaring	Transportation	Storage	Refining
Western Europe	300–5,000	1,000–3,000	745	90–1,400	20–250
United States and Canada[a]	300–5,000	3,000–14,000[a]	745	90–1,400	20–250
FSU, Central and Eastern Europe	300–5,000	—	745	90–1,400	20–250
Other oil-exporting countries	300–5,000	—	745	90–1,400	20–250
Rest of the world	300–5,000	—	745	90–1,400	20–250

Source: IPCC, 1996. Adapted from Table 1-58 in 1996 Revised Guidelines Reference Manual.
FSU = Former Soviet Union.
[a] In the United States and Canada, venting and flaring emissions are based on total production of both oil and gas produced.

US EPA (2006) Global Mitigation of Non-CO2 Greenhouse Gases, Jun06, page II-36.

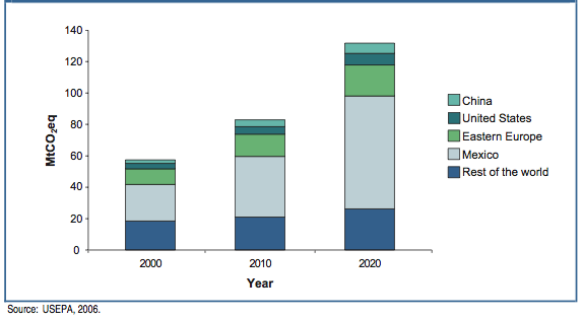
Table 3-1: Total CH_4 Emissions from Natural Gas and Oil Systems ($MtCO_2e$)

Gas	1990	1995	2000	2005	2010	2015	2020	2025	2030
Total CH_4	1,165.4	1,219.8	1,325.7	1,462.6	1,595.2	1,699.5	1,788.9	1,887.0	1,971.6

CMS note: the EPA (2011) report does not disaggregate methane emissions in the energy sector to natural gas and oil
The combined oil and gas CH4 emissions are ~15% higher in EPA (2006) report (sum of Tables 20 & 21).

EPA 2011 Source Description, page 3-3.

Figure 3-1: CH_4 Emissions from Oil Production by Country: 2000–2020



Source: USEPA, 2006.

Table 3-5: Baseline Emissions from Oil Production, by Country: 1990–2000 ($MtCO_2eq$)

Country	1990	1995	2000
Mexico	18.8	19.3	23.3
Romania	20.1	11.4	8.3
China	1.2	1.4	2.2
United States	4.4	4.1	3.9
Nigeria	0.9	1.0	1.8
Iran	1.3	1.6	1.2
Kuwait	0.4	0.8	1.0
United Arab Emirates	1.1	1.2	1.2
Indonesia	1.2	1.0	1.9
Iraq	1.1	0.3	0.9
Ecuador	0.3	0.3	0.5
Canada	0.8	0.8	0.9
Bulgaria	0.6	0.7	0.6
Russian Federation	1.7	0.9	0.6
Lithuania	0.5	0.5	0.4
Rest of the world	**8.2**	**8.2**	**8.7**
World Total	**62.6**	**53.5**	**57.4**

Source: USEPA, 2006.

US EPA (2006) Global Mitigation of Non-CO2 Greenhouse Gases, Jun06, page II-38.

Table 3-6: Projected Baseline Emissions from Oil Production by Country: 2005–2020 ($MtCO_2eq$)

Country	2005	2010	2015	2020
Mexico	27.7	38.7	54.1	71.9
Romania	9.3	12.0	14.7	17.3
China	2.9	4.4	6.1	6.5
United States	3.4	3.7	4.1	4.5
Nigeria	2.2	2.7	3.3	4.1
Iran	1.8	2.2	2.7	3.6
Kuwait	1.0	1.3	1.4	1.8
United Arab Emirates	1.2	1.2	1.4	1.7
Indonesia	1.9	1.8	1.6	1.4
Iraq	0.8	0.9	1.0	1.3
Ecuador	0.6	0.6	0.8	1.1
Canada	0.9	0.9	1.0	1.0
Bulgaria	0.7	0.8	0.9	1.0
Russian Federation	0.7	0.8	0.9	1.0
Lithuania	0.6	0.6	0.7	0.8
Rest of the world	**9.1**	**10.1**	**11.4**	**12.9**
World Total	**64.7**	**82.9**	**106.1**	**131.8**

Source: USEPA, 2006.

US EPA (2006) Global Mitigation of Non-CO2 Greenhouse Gases, Jun06, page II-38.

Petroleum

EPA data on US methane emissions from petroleum systems

U.S. Environmental Protection Agency (2012) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010, 481 pp., Apr12, plus annexes.
epa.gov/climatechange/emissions/usinventoryreport.html

The EPA 2012 data is used in preference to the 2006 data in Table 21 --
primarily due the recent efforts to use monitored data and the awareness of higher methane emissions

Table 30 — **US methane emissions & rates from Petroleum Systems**

Gg = million kg	Oil production	CH4 emissions	Methane rate	Oil emissions	Methane rate
	million bbl	million kg CH4	kg CH4/bbl	MtCO2	kg CH4/tCO2
	Crude & NGPL	EPA Table A-141	calculated	calculated	calculated
1990	2,685	1,677	0.62	997	1.68
1995	2,394	1,581	0.66	889	1.78
2000	2,125	1,492	0.70	789	1.89
2006	1,862	1,389	0.75	692	2.01
2007	1,848	1,420	0.77	687	2.07
2008	1,807	1,427	0.79	671	2.13
2009	1,957	1,460	0.75	727	2.01
2010	2,012	1,478	0.73	747	1.98
Average	**2,086**	**1,491**	**0.72**	**775**	**1.94**
	EIA data	EPA data			
Totals	16,690	11,924		6,199	
	Weighted average		**0.71**		**1.924** kg CH4/tCO2

Source for Final CH4 Table 6

CMS factor for oil & NGL emissions: 0.3714 tCO2 per bbl
linked to SumOil.xls

EPA (2012)
Table 3-46
Monte Carlo Sim

Source	Gas	2010 Emission Estimate (Tg CO_2 Eq.)[b]	Uncertainty Range Relative to Emission Estimate[a] (Tg CO_2 Eq.) Lower Bound[b]	(Tg CO_2 Eq.) Upper Bound[b]	(%) Lower Bound[b]	(%) Upper Bound[b]
Petroleum Systems	CH_4	31.05	23.64	77.31	-24%	149%
Petroleum Systems	CO_2	0.34	0.26	0.85	-24%	149%

Table A-141: Summary of CH_4 Emissions from Petroleum Systems (Gg)

Activity	1990	1995	2000	2006	2007	2008	2009	2010
Production Field Operations	**1,653**	**1,557**	**1,467**	**1,365**	**1,396**	**1,404**	**1,437**	**1,455**
Pneumatic device venting	489	463	428	396	398	416	419	420
Tank venting	250	226	214	188	192	182	206	214
Combustion & process upsets	88	82	76	71	72	75	94	97
Misc. venting & fugitives	799	762	726	692	714	706	693	700
Wellhead fugitives	26	25	22	17	20	24	24	24
Crude Oil Transportation	**7**	**6**	**5**	**5**	**5**	**5**	**5**	**5**
Refining	**18**	**18**	**19**	**19**	**19**	**19**	**18**	**19**
Total	**1,677**	**1,581**	**1,492**	**1,389**	**1,420**	**1,427**	**1,460**	**1,478**

Note: Totals may not sum due to independent rounding.

EPA (2012) Inventory of U.S. Emissions and Sinks 2010 (Final, Apr12), Annex 3,
Table A-141: Summary of CH4 emissions from Petroleum Systems (Gg)

Natural Gas

EPA data on US methane emissions from natural gas systems

U.S. Environmental Protection Agency (2012) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010, 481 pp., Apr12, plus annexes.
epa.gov/climatechange/emissions/usinventoryreport.html

Table 23 and pngs of EPA (2012) annex tables 19July2012

Table 31 — **EPA data on vented and fugitive CH4 from natural gas systems, U.S. 1990-2010**

Gg CO2 = thousand tCO2

	Natural gas production, Table A-129	Natural gas processing, Table A-130	Natural gas trans & storage, Table A-131	Natural gas distribution, Table A-132	Total emissions, natural gas systems	Total -- excluding distribution	Methane rate: CH4 per Bcf of U.S. gas
			Natural gas				
EPA	MtCH4	MtCH4	MtCH4	MtCH4	MtCH4	MtCH4	tCH4/Bcf
1990	4.233	0.853	2.34302	1.5911	9.020	**7.429**	**417.1**
1992	4.352	0.848	2.37533	1.5682	9.144	**7.575**	**424.6**
1995	4.809	0.869	2.44157	1.5619	9.682	**8.120**	**436.6**
2000	6.010	0.877	2.48131	1.5243	10.893	**9.369**	**488.4**
2006	7.669	0.841	2.42856	1.3935	12.332	**10.938**	**591.1**
2007	8.303	0.869	2.47802	1.4373	13.087	**11.650**	**604.7**
2008	8.642	0.902	2.50251	1.4539	13.501	**12.047**	**593.9**
2009	8.839	0.918	2.49856	1.4250	13.681	**12.256**	**595.5**
2010	8.792	0.955	2.52461	1.4101	13.682	**12.272**	**568.7**
Total 1990-2010	61.649	7.933	22.073	13.365	105.021	**91.655**	
average	6.850	0.881	2.453	1.485	11.669	**10.184**	**527.8**
percent of total	67.3%	8.7%	24.1%	14.6%	114.6%	**100%**	

US EPA CH4 from natural gas systems for 1990: 220 Bcf For 2010: 791 Bcf
Harvey (2012) Leaking Profits, p. 12.

Table 32 — **Calculation of natural gas system methane rates**

	U.S. natural gas production, EIA data	Estimated CO2 emissions from U.S. natural gas prodn	Methane emission rate (excluding distribution CH4)	Methane emission rate (excl. distrib.	Methane emission rate (excl. distrib.
	Bcf/yr	MtCO2/yr	kg CH4/tCO2	g CH4/cf	Percent
1990	17,810	952	**7.81**	0.417	2.17%
1992	17,840	953	**7.95**	0.425	2.20%
1995	18,599	994	**8.17**	0.437	2.27%
2000	19,182	1,025	**9.14**	0.488	2.54%
2006	18,504	989	**11.06**	0.591	3.07%
2007	19,266	1,029	**11.32**	0.605	3.14%
2008	20,286	1,084	**11.11**	0.594	3.08%
2009	20,580	1,100	**11.14**	0.596	3.09%
2010	21,577	1,153	**10.64**	0.569	2.95%
Total 1990-2010	173,644	9,278	**88.35**		
average	19,294	1,031	**9.82**	0.5278	2.72%
Weighted average of 1990-2010			**9.878**	0.5312	1.54%

Linked to Table 6
Bradbury et al 2013

tCH4/Bcf = gCH4/cf

Table A-130: CH_4 Emission Estimates from the Natural Gas Processing Plants Excluding Reductions from the Natural Gas STAR Program, Regulations, and Non-Gas STAR Reductions (Gg)

Activity	1990	1992	1995	2000	2006	2007	2008	2009	2010
Normal Fugitives									
Plants	42.30	40.68	37.52	32.51	31.74	31.90	32.07	32.18	32.51
Reciprocating Compressors	324.94	324.74	338.42	349.51	337.12	351.55	368.88	376.77	395.75
Centrifugal Compressors (wet seals)	240.29	240.15	248.60	251.32	229.92	230.99	232.27	232.85	234.26
Centrifugal Compressors (dry seals)	0.00	0.00	0.81	3.50	9.50	14.21	19.87	22.44	28.64
Vented and Combusted									
Normal Operations									
Compressor Exhaust									
Gas Engines	137.10	137.02	142.79	147.47	142.24	148.33	156.64	158.97	166.98
Gas Turbines	3.86	3.86	4.02	4.15	4.01	4.18	4.38	4.48	4.70
AGR Vents	16.49	15.87	14.63	12.68	12.38	12.44	12.51	12.55	12.68
Kimray Pumps	3.68	3.68	3.83	3.96	3.82	3.98	4.18	4.27	4.48
Dehydrator Vents	22.66	22.65	23.60	24.38	23.51	24.52	25.73	26.28	27.60
Pneumatic Devices	2.41	2.32	2.14	1.86	1.81	1.82	1.83	1.84	1.86
Routine Maintenance									
Blowdowns/Venting	59.51	57.24	52.78	45.74	44.65	44.88	45.12	45.28	45.74
Total	**853.24**	**848.20**	**869.16**	**877.08**	**840.69**	**868.81**	**902.47**	**917.89**	**955.20**

Note: Totals may not sum due to independent rounding.

CMS factor for natural gas combustion 0.0534 MtCO2 per Bcf
linked to SumGas.xls

19,260 tonnes CH4/Bcf
51.92 Bcf/MtCH4

EPA (2012) Inventory of U.S. Emissions and Sinks 2010 (Final, Apr12), Annex 3,
Table A-130: CH4 Emission Estimates from the Natural Gas Processing Plants
Excluding Reductions from the Natural Gas STAR Program, Regulations, and Non-Gas STAR Reductions (Gg)

Jonah Field, Wyoming (National Geographic)

Background data used in Table 23

Table A-129: CH_4 Emission Estimates from the Natural Gas Production Stage Excluding Reductions from the Natural Gas STAR Program, Regulations, and Non-Gas STAR Reductions (Gg)

Activity	1990	1992	1995	2000	2006	2007	2008	2009	2010
Normal Fugitives									
Associated Gas Wells	+	+	+	+	+	+	+	+	+
Non-Associated Gas Wells (less wells with hydraulic fracturing)	22.10	23.62	27.84	36.84	36.72	36.63	43.31	44.50	42.10
Gas Wells with Hydraulic Fracturing	0.033	0.064	0.178	1.400	7.974	9.385	9.148	10.81	10.81
Field Separation Equipment									
Heaters	12.57	13.28	16.48	23.56	28.02	28.38	34.12	34.95	33.02
Separators	43.83	44.16	54.79	76.51	90.27	94.13	109.28	112.26	107.90
Dehydrators	14.75	15.76	17.89	20.77	24.94	26.18	28.53	29.44	29.29
Meter/ Piping	43.61	44.95	54.89	73.80	87.21	90.27	104.95	107.71	103.51
Gathering Compressors									
Small Reciprocating Comp.	30.22	32.15	38.27	45.57	56.12	58.50	66.24	68.51	66.22
Large Reciprocating Comp.	7.50	8.56	9.80	11.70	12.59	12.71	13.79	13.54	14.49
Large Reciprocating Stations	0.51	0.58	0.66	0.79	0.85	0.86	0.93	0.92	0.98
Pipeline Leaks	98.03	102.22	114.49	133.58	153.00	160.06	175.25	179.71	176.68
Vented and Combusted									
Drilling and Well Completion									
Gas Well Completions without Hydraulic Fracturing	0.005	0.006	0.006	0.007	0.009	0.009	0.010	0.011	0.010
Gas Well Completions with Hydraulic Fracturing	16.35	23.81	31.23	413.6	711.1	831.1	648.0	511.4	511.4
Well Drilling	0.74	0.54	0.53	1.01	1.85	1.89	1.93	1.10	1.08
Produced Water from Coal Bed Methane Wells									
Powder River	0.04	0.47	1.48	31.39	60.94	60.93	55.36	64.80	64.80
Black Warrior	2.72	4.84	6.25	6.82	10.45	11.09	11.69	12.06	12.30
Normal Operations									
Pneumatic Device Vents	569.76	607.88	697.61	810.83	991.63	1,043.63	1,163.70	1,205.74	1,182.54
Chemical Injection Pumps	26.89	29.38	35.04	43.44	53.95	54.95	64.46	66.39	63.43
Kimray Pumps	131.82	140.65	159.45	185.01	222.10	233.43	254.28	262.49	261.14
Dehydrator Vents	41.10	43.86	49.72	57.69	69.26	72.78	79.29	81.85	81.43
Condensate Tank Vents									
Condensate Tanks without Control Device	77.69	59.56	58.09	67.47	109.76	114.96	135.58	137.65	137.65
Condensate Tanks with Control Device	15.54	11.91	11.62	13.49	21.95	22.99	27.12	27.53	27.53
Compressor Exhaust Vented									

Activity	1990	1992	1995	2000	2006	2007	2008	2009	2010
Gas Engines	119.06	125.48	151.43	180.03	224.23	235.27	265.92	274.78	267.82
Well Workovers									
Gas Wells without Hydraulic Fracturing	0.56	0.58	0.64	0.73	0.87	0.94	1.02	1.05	1.05
Gas Wells with Hydraulic Fracturing	3.192	7.450	16.40	99.40	542.7	636.0	652.3	727.3	727.3
Well Clean Ups (LP Gas Wells)	2,652	2,699	2,931	3,328	3,974	4,127	4,360	4,548	4,564
Blowdowns									
Vessel BD	0.36	0.38	0.42	0.49	0.58	0.62	0.68	0.71	0.70
Pipeline BD	1.56	1.63	1.82	2.13	2.44	2.55	2.79	2.86	2.81
Compressor BD	1.17	1.24	1.48	1.76	2.17	2.26	2.56	2.65	2.56
Compressor Starts	2.61	2.78	3.31	3.94	4.85	5.05	5.72	5.92	5.72
Upsets									
Pressure Relief Valves	0.34	0.35	0.39	0.45	0.53	0.57	0.62	0.65	0.64
Mishaps	0.85	0.88	0.99	1.15	1.32	1.38	1.51	1.55	1.52
Offshore									
Offshore water Gas Platforms (GoM & Pacific)	290.49	297.84	307.33	323.74	321.18	305.17	299.06	278.32	266.07
Deepwater Gas Platforms (GoM & Pacific)	5.21	5.94	7.40	12.81	23.20	21.10	21.78	22.39	22.95
Total	**4,232.74**	**4,351.92**	**4,809.17**	**6,010.21**	**7,669.11**	**8,302.90**	**8,642.02**	**8,839.28**	**8,791.85**

Note: Totals may not sum due to independent rounding.

EPA (2012) Draft Inventory of U.S. Emissions and Sinks 2010,
Annex 3: Methodological Descriptions for Additional Source or Sink Categories,
Table A-129: CH4 Emission Estimates from the Natural Gas Production Stage Excluding Reductions from the Natural Gas STAR Program, Regulations, and Non-Gas STAR Reductions (Gg)

Table A-131: CH_4 Emission Estimates from the Natural Gas Transmission and Storage Excluding Reductions from the Natural Gas STAR Program, Regulations, and Non-Gas STAR Reductions (Gg)

Activity	1990	1992	1995	2000	2006	2007	2008	2009	2010
Fugitives									
Pipelines Leaks	3.19	3.18	3.24	3.27	3.28	3.29	3.31	3.33	3.33
Compressor Stations (Transmission)									
Station	106.96	106.77	108.77	109.51	110.02	110.28	111.09	111.51	111.51
Recip Compressor	744.89	743.55	757.53	762.66	766.19	768.04	773.65	776.60	776.60
Centrifugal Compressor (wet seals)	246.76	246.32	249.68	245.59	236.80	236.86	237.05	237.14	237.14
Centrifugal Compressor (dry seals)	0.00	0.00	0.81	4.53	10.92	11.27	12.34	12.91	12.91
Compressor Stations (Storage)									
Station	54.64	58.36	60.35	62.17	54.36	58.76	60.87	59.45	61.62

Activity	1990	1992	1995	2000	2006	2007	2008	2009	2010
Recip Compressor	157.80	168.48	174.27	179.62	157.05	169.67	175.76	171.75	177.98
Centrifugal Compressor (wet seals)	33.22	35.46	36.55	34.41	27.39	27.65	27.78	27.14	27.27
Centrifugal Compressor (dry seals)	0.00	0.00	0.13	2.54	4.10	5.72	6.53	6.53	7.34
Wells (Storage)	13.56	14.49	14.98	15.43	13.49	14.59	15.11	14.76	15.30
M&R (Trans. Co. Interconnect)	72.80	72.67	74.03	74.53	74.88	75.06	75.61	75.90	75.90
M&R (Farm Taps + Direct Sales)	16.90	16.87	17.19	17.31	17.39	17.43	17.56	17.62	17.62
Vented and Combusted									
Normal Operation									
Dehydrator Vents (Transmission)	1.99	1.99	2.03	2.04	2.05	2.06	2.07	2.08	2.08
Dehydrator Vents (Storage)	4.23	4.51	4.67	4.81	4.20	4.54	4.71	4.60	4.77
Compressor Exhaust									
Engines (Transmission)	176.92	186.65	204.91	215.30	200.09	213.12	214.70	210.74	222.68
Turbines (Transmission)	1.00	1.06	1.16	1.22	1.13	1.21	1.22	1.19	1.26
Engines (Storage)	21.30	22.75	23.53	24.24	21.19	22.91	23.73	23.18	24.02
Turbines (Storage)	0.18	0.19	0.20	0.20	0.18	0.19	0.20	0.19	0.20
Generators (Engines)	8.66	9.13	10.03	10.54	9.79	10.43	10.51	10.31	10.90
Generators (Turbines)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pneumatic Devices Trans+Stor									
Pneumatic Devices Trans	213.13	212.75	216.75	218.21	219.23	219.75	221.36	222.20	222.20
Pneumatic Devices Storage	44.44	47.46	49.09	50.56	44.21	47.79	49.51	48.36	50.12
Routine Maintenance/Upsets									
Pipeline Venting	177.99	177.67	181.01	182.24	183.08	183.52	184.86	185.57	185.57
Station venting Trans+Storage									
Station Venting Transmission	145.52	145.26	147.99	148.99	149.68	150.04	151.13	150.71	151.71
Station Venting Storage	30.34	32.41	33.51	34.52	30.18	32.63	33.80	33.01	34.22
LNG Storage									
LNG Stations	9.24	9.45	9.77	10.30	10.62	10.62	10.62	10.62	10.62
LNG Reciprocating Compressors	34.50	35.37	36.67	38.84	40.15	40.15	40.15	40.15	40.15
LNG Centrifugal Compressors	11.78	12.09	12.55	13.31	13.77	13.77	13.77	13.77	13.77
LNG Compressor Exhaust									
LNG Engines	2.59	2.61	2.63	2.66	2.68	2.68	2.68	2.68	2.68
LNG Turbines	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
LNG Station Venting	5.13	5.25	5.43	5.72	5.90	5.90	5.90	5.90	5.90
LNG Import Terminals									
LNG Stations	0.21	0.21	0.21	0.21	0.42	0.42	1.06	1.16	1.16
LNG Reciprocating Compressors	1.01	1.01	1.01	1.01	2.02	2.02	5.05	5.55	5.55
LNG Centrifugal Compressors	0.26	0.26	0.26	0.26	0.52	0.52	1.29	1.42	1.42
LNG Compressor Exhaust									
LNG Engines	1.74	0.96	0.49	4.41	11.28	14.81	6.91	8.80	8.41
LNG Turbines[1]	0.01	0.00	0.00	0.03	0.07	0.09	0.04	0.05	0.05
LNG Station Venting	0.12	0.12	0.12	0.12	0.24	0.24	0.59	0.65	0.65
Total	**2,343.02**	**2,375.33**	**2,441.57**	**2,481.31**	**2,428.56**	**2,478.02**	**2,502.51**	**2,498.56**	**2,524.61**

[1] Emissions are not actually 0, but too small to show at this level of precision.
Note: Totals may not sum due to independent rounding.

Annex 3: Methodological Descriptions for Additional Source or Sink Categories,
Table A-131: CH4 Emission Estimates from the Natural Gas Transmission and Storage Excluding Reductions from the 8 Natural Gas STAR Program, Regulations, and Non-Gas STAR Reductions (Gg)

Cell: Q28
Comment: Rick Heede:
These are regional estimates, since OGP does not provide a regional or global oil:gas ratio. In fact, global emissions from the OGP production is also an estimate based on our use of OGP's general statement that "OGP members produce more than half the world's oil and about one third of its gas." See Table 9.

Cell: G29
Comment: Rick Heede:
Conversion from BP Statistical Yearbook, glossary.

Cell: C88
Comment: Rick Heede:
If 58.3 kg of CO2 results from the combustion of 1,000 cf of natural gas, and 1 tonne of natural gas contains 52,470 cf, then 58.3 * 52.47 = 3.07 tonnes of CO2 results from the combustion of 1 tonne of natural gas. CMS uses this factor to estimate OGP oiłgas ratio. Bcf per tonne of CO2 emissions from conversion tables below.

Cell: E230
Comment: Rick Heede:
Shell HSE Data Tables, The Shell Report 2002, p. 46.

Cell: F231
Comment: Rick Heede:
Shell, operating data 1999-2003, p. 46, in million tonnes and bbłday. 2003: 2.379 million bbl per day = 119 million tonnes per year.

Cell: D245
Comment: Rick Heede:
Shell "Performance Data" at Royal Dutch Shell plc Sustainability Report 2010. Direct methane emissions 2011-2010 in thousand tonnes.

Cell: J254
Comment: Rick Heede:
Shell SustRpt 2010, page 29: "We estimate that the CO2 emissions from the use of the products we made were around 670 million tonnes in 2010."

Cell: O257
Comment: Rick Heede:
Shell Rpt 2010, p 11: "We are also involved in plans for full-scale CCS projects. The Gorgon LNG project (Shell interest 25%) will include the world's largest CCS project. It will capture nearly 3.8 million tonnes a year of CO2 produced with the natural gas, and store it more than 2 km underground. The CCS project has received A$60 million in financial support from the Australian govt." P.12: "The Gorgon LNG project (Shell interest 25%) at Barrow Island off Western Australia will produce 15 million tonnes a year of LNG for around 40 years – around 8% of current global LNG capacity and enough to power 38 million homes a year. Gorgon will include the world's largest carbon capture and storage (CCS) project, reducing the project's overall CO2 emissions by around 40%." At (BP) 48.7 Bcf per Mt LNG; 15 MtLNG/yr = 730.5 Bcf; at CMS rate of 0.057522 MtCO2 per Bcf, 730.5 Bcf = 42.02 MtCO2. Thus, crudely (not accounting for LNG plant combustion CO2), if 3.8 MtCO2 is 40 percent of Gorgon, then 100% is 8.5 MtCO2, and equiv to 8.5/40 = 21.24%.

Cell: D260
Comment: Rick Heede:
ExxonMobil Corp (2005) Corporate Citizenship Report, 72 pp.
Normalized emissions of "Direct-Equity CO2-equiv emissions (excl cogeneration)" 2002-2005 listed below; p. 25.
Emissions in opaque column charts, p. 24: 2005 is ~140 million tonnes "Direct-Equity CO2-equiv emissions" and downstream totals ~48 MtCO2-e, upstream ~48 MtCO2-e, and Chems ~24 MtCO2-e.
Flaring, p. 27, rose to 784 million cf per day in 2005. Increase is 10 percent above 2004 (Nigeria) and equals 2.1 MtCO2/yr.
VOCs column chart, p. 31, upstream = ~0.085 tonnes per 100 tonnes of throughput, refining ~0.015, chems ~0.048 tonnes per 100 tonnes of throughput.

Cell: K263
Comment: Rick Heede:
ExxonMobil CDP rpt for 2010, section 12.3. Fuel breakdown: 27 million GWh of refinery gas, 13 million GWh natural gas, and 9 million GWh other types.

Cell: C265
Comment: Rick Heede:
in FOE folder, Emissions & Climate, XOMGHGbarchart2001.pdf.

Cell: K268
Comment: Rick Heede:
CDP 2010, section 15.1: "NOTE: THIS IS NOT TOTAL CORPORATION DATA. ONLY NEW ZEALAND SCOPE 3 SUBMITTED UNDER REGULATORY REPORTING REQUIREMENT. According to the International Energy Agency, approximately 90 percent of petroleum-related GHG emissions are generated when customers use our products and the remaining 10 percent are generated by industry operations."

Cell: C275
Comment: Rick Heede:
"For 2003, ChevronTexaco's total net emissions were approximately 64 million metric tons of CO2 equivalents. This is based on ChevronTexaco's equity share in those businesses and operations in which it has financial interests and over which it either has operational control or which report GHG emissions using a compatible protocol. In 2003, 89 percent of CO2 equivalent emissions were from CO2 and approximately 11 percent from methane, with trace amounts of nitrous oxide."
www.chevrontexaco.com/cr_report/2003/climate_change.asp

Cell: B292
Comment: Rick Heede:
BP (2005) Detailed Performance Data; "A full breakdown for all GHG data, including CO2, methane, direct and indirect emissions for the last 7 years is given in our charting tool."

Cell: G293
Comment: Rick Heede:
GHG emissions in tonnes per thousand bbl per day refinery throughput.

Cell: H293
Comment: Rick Heede:
GHG emissions in tonnes per thousand tonnes chemicals production (in Utilized Equivalent Distillation Capacity).

Cell: G309
Comment: Rick Heede:
BP annual sust rpt, 2005, Fiver-year performance data, p. 60, list indirect CO2 for 2001-2005 only. Other details on direct CO2 and direct methane from BP charts 1998-2005 plus tables.

Cell: B310
Comment: Rick Heede:
BP (2005) Detailed Performance Data; "A full breakdown for all GHG data, including CO2, methane, direct and indirect emissions for the last 7 years is given in our charting tool."

Cell: K311
Comment: Rick Heede:
GHG emissions in tonnes per thousand bbl per day refinery throughput.

Cell: L311
Comment: Rick Heede:
GHG emissions in tonnes per thousand tonnes chemicals production (in Utilized Equivalent Distillation Capacity).

Cell: I328
Comment: Rick Heede:
BP's emissions website: "Using the revised methodology we estimate CO2 emissions from BP products at around 570Mte in 2005; on the same basis the figure for 2004 would have been 606Mte and for 2003 614 Mte."
Note: BP does not discount emissions for incomplete combustion or for non-fuel uses. Since CMS does account for both adjustments, CMS estimates will be ~4 percent lower than BP's estimates.

Cell: O330
Comment: Rick Heede:
Published emissions of methane per tonne of carbon dioxide emitted by combustion of BP's oil and natural gas production, for each year 1998-2005. Note: methane emissions arise from both oil and gas upstream operations, and although often in greater proportion from gas operations, BP (like other oil & gas companies) does not provide details on methane sources. Hence CMS, as a first step, divides both methane and carbon dioxide emissions by combined oil and gas product emissions.

Cell: F344
Comment: Rick Heede:
O&GP 2003 data provides data on air and water emissions and a few other benchmarking datasets based on survey responses by 35 of O&GP member companies. Since O&GP oil and gas production data are in gross production, and the global data from BP Statistic review is reported in net production, the reported proportion of total production is somewhat lower than the stated 41 percent.
Note: the regional response rate, and thus reported emissions and the total production to which emissions are compared, varies from 11 percent in FSU, and 16 percent in the Middle East, to 51 and 99 percent in North America and Europe, respectively.
International Association of Oil and Gas Producers (2004) Environmental Performance in the E&P Industry, 2003 Data, Rpt 359, 30 pp., London, www.ogp.org.uk

Cell: K345
Comment: Rick Heede:
IGP 2003 data Appendix shows total CO2 and CH4 emissions by its members, plus the calculated emissions rate in kg per tonne of oil plus gas produced. Global methane rate averaged 1.252 kg per tonne of production, but high regional variation:
Africa = 2.03 kg/tonne
Asia/Aus = 2.79 kg/t
Europe = 0.24 kg/t
FSU = 1.79 kg/t
Middle East = 0.47 kg/t
North America = 1.16 kg/t
South America = 1.47 kg/t

Cell: J348
Comment: Rick Heede:
CMS estimates full combustion of crude oil emits 0.492 tonnes CO2 per bbl. Natural gas = 0.0583 tonnes CO2 per 1,000 cf. See worksheets in SumOil.xls and SumGas.xls -- "Emission Factor Calc" -- for details.

Cell: M350
Comment: Rick Heede:
OGP data are used appropriately as emissions rate for oil & gas production combined (as done in yellow below), but it does not follow that attributing emissions on the basis of relative production of oil and gas is sound, and is shown for illustration only.

Cell: M354
Comment: Rick Heede:
Also CO2 emissions by activity. Also emissions of both CO2 and methane emissions (and prod) onshore vs offshore; onshore prod = 1.05 Gt, offshore 1.21 Gt. Methane rate onshore = 1.27 t per thousand tonnes, vs offshore 1.16 t/kt.

Cell: J364
Comment: Rick Heede:
OGP regional methane emissions data in Column D (kg CH4 per tonne of production divided by CO2 emissions per tonne of production equals kg CH4 per tonne of CO2.

Cell: J372
Comment: Rick Heede:
CMS uses this global estimated average methane emissions rate to estimate "ancillary methane" on the SumRanking.xls worksheet. This is preliminary until other CH4 emission rates can be evaluated.

Cell: K404
Comment: Rick Heede:
Kirchgessner, David A., Robert A. Lott, R. Michael Cowgill, Matthew R. Harrison, & Theresa M. Shires (1997) "Estimate of Methane Emissions from the U.S. Natural Gas Industry," Chemo-sphere, vol. 35:1365-1390; also US EPA: AP 42, 5th edition, vol. 1 chapter 14: Biogenic Sources; www.epa.gov/ttn/chief/ap42/ch14/

Cell: F407
Comment: Rick Heede:
EIA (2006) Annual Review of Energy, Table 6.2, shows U.S. natural gas production; 1994 total = 23.581 Tcf (of which 17.35Tcf is from gas wells, and 6.230 Tcf from oil wells). CMS uses "Dry Gas Production" totaling 18.821 Tcf in 1994.

Cell: J418
Comment: Rick Heede:
American Petroleum Institute (2001) Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Gas Industry, written for API by Harris, Graham, Theresa Shires, & Chris Loughran, URS Corp., Austin TX, 196 pp. While this document is linked to IPIECA's Guidelines, the latter is chiefly a protocol doument whereas the former provides numerous emissions factors and numerous practical examples of industry emissions on a flow basis. These are not industry averages, but are nonetheless cited and converted to common units to help provide background for emissions rates of methane and carbon dioxide per unit of production of oil and gas.
International Petroleum Industry Environmental Conservation Association (2003) Petroleum Industry Guidelines for Reporting Greenhouse Gas Emissions.

Cell: C420
Comment: Rick Heede:
The API Compendium also calculates emissions from two additional facilities -- gas compressor at a gas field gathering pipeline station (17,194 tonnes CO2-eq, of which 73.3 percent is CO2) and a marketing terminal facility (loading capacity of 90 trucks @10,000 gallons pr day, or 7.82 million bbl per yr with emissions totaling 5,311 tonnes CO2-eq; nearly all CO2, with chief sources being road tankers [3,126 tonnes CO2/yr] and the vapor combustion unit [VCU: 2,111 tC)2/y]). These two facilities are not included in the examples listed below.

Cell: Q420
Comment: Rick Heede:
Methane emissions rates are calculated as CH4 in CO2-eq units as percent of CO2 emissions from product combustion.

Cell: B421
Comment: Rick Heede:
API (2001) Compendium, pp 5.1-5.13 calculates emissions from an "Onshore Oil Field with high CO2 content" that contains 320 producing oil wells. Emissions from combustion, point sources, fugitive emissions, and non-routine emissions for both carbon dioxide and methane are all calculated. Annual emissions total 97,580 tonnes of CO2-eq, and the chief sources includes flares (28,420 tonnes CO2) and tank flashing losses (1,852 tonnes of CH4 = 38,892 tonnes CO2-eq). Of the total (97,580 tonnes CO2-eq), 57 percent is methane, and 43 percent is CO2.
Oil production averages 6,100 bbl per day (2.23 million bbl$yr), which -- at 0.429 MtCO2 per million bbl of product emissions (as calculated by CMS) -- equals 0.957 MtCO2. Gas production of 30 million cubic feet per day (10.95 Bcf/yr) equals -- at 0.0583 MtCO2 per Bcf (again as calculated by CMS) -- totals product emissions of 0.638 MtCO2. Oil and gas product emissions totals 1.595 MtCO2.
Thus, process emissions totaling 97,580 tonnes CO2-eq is equal to 6.12 percent, of which the emitted methane represents 6.12*0.569 = 3.48 percent and CO2 = 6.12*0.431 = 2.64 percent.

Cell: B422
Comment: Rick Heede:
API (2001) Compendium, pp 5.14-5.23 calculates emissions from an offshore platform with 72 oil- and gas-producing wells. Gas production totals 12 million cf/d (4.38 Bcf) and oil production totals 67.89 million bbl$yr (assuming that reported 36,000 bbl per day dry oil + 150,000 bbl per day of "oil emulsion" is reporting oil production only). Emissions total 60,179 tonnes of methane -- chiefly tank flashing losses -- and 8,823 tonnes of CO2 from combustion (service boats and helicopters) and flares.

Cell: B423
Comment: Rick Heede:
API (2001) Compendium, pp 5.23-5.33 describes a natural gas processing plant with a throughput of 800 million cf per day (0.8 Bcf/d = 292 Bcf/yr). Produced gas CH4 content is 70 mole %, and the processed gas CH4 content is 90 mole %. CO2 in the produced gas is 3.5 mole % and send-out gas is 2.5 mole %. Carbon emissions from purchased electricity is stated as unknown.
The principal process emissions sources include external combustion (184,686 tonnes CO2), internal combustion (260,888 tonnes CO2), and sour gas processing (298,715 tonnes CO2).

Cell: B424
Comment: Rick Heede:
API (2001) Compendium, pp 5.46-5.52 calculates emissions from an oil refinery with a throughput of 250,000 bbl per day (91.25 million bbl$yr). Combustions sources are fired with "refinery fuel gas or natural gas." Emissions are chiefly CO2 from combustion sources (steam boilers and gas turbines), flaring (153,709 tonnes CO2) and venting (catalytic cracking regeneration vent of 1,973400 tonnes CO2).

Cell: K430

Comment: Rick Heede:
While this is an oil and gas production platform, oil production accounts for 99.1 percent of the tonnes produced as well as 99.2 percent of total process emissions (via tank flashing losses alone).

Cell: J437
Comment: Rick Heede:
EIA (2006) Emissions of GHG 2005, Tables 17 and 18 of Methane chapter. Reported in million tonnes of CH4 gas per year. EIA is using a GWP factor of 23xCO2 (change since 2004 edition, and contrary to IPCC SAR and industry practice of using 21xCO2 per SAR).

Cell: F462
Comment: Rick Heede:
Straight conversion from percent to kg per tonne.

Cell: G462
Comment: Rick Heede:
1 Mt of gas production = 3.0543 MtCO2 emitted. CMS divides kgCH4 emitted from natural gas industry by the above factor.

Cell: L463
Comment: Rick Heede:
This presumably includes only vented CO2 from entrained gas.

Cell: P464
Comment: Rick Heede:
EIA uses the IPCC FAR GWP factor of methane 23xCO2.

Cell: C465
Comment: Rick Heede:
This estimate is hampered by lack of an oil:gas ratio upon which OGP reports emissions (only the total production is reported. Nor does OGP state its emissions reporting protocol, boundary, or offshore/onshore ratio. CMS coverts this compromised data into estimated oil:gas production in order estimate total CO2 emissions from the combustion of the oil and gas produced. See Tables 7, 8, and 9 for details.

Cell: J465
Comment: Rick Heede:
EIA (2006) Emissions of Greenhouse Gases in the United States 2005, Table 5.

Cell: O465
Comment: Rick Heede:
EIA (2006) Emissions in the US, Table 17. "U.S. Methane Emissions from Natural Gas Systems" totals 6.7 million tonnes CH4 in 2005(P), of which 1.87 from production, 0.63 from gas processing, 2.34 from transmission and storage, and 1.85 from distribution.

Cell: C468
Comment: Rick Heede:
EPA, cited in Delucchi, forecast for US in 2000 (high gas use):
Production: 0.31 percent,
Transmission: 0.22 percent,
Distribution: 0.07 percent.
CMS uses production plus one-half of transmission emissions: 0.42 percent.

Cell: C469
Comment: Rick Heede:
GRI, cited in Delucchi, estimate for US: Production plus Transmission plus Distribution: 1.0 to 2.0 percent.
CMS assumes EPA's proportions for production, transmission, and distribution (i.e., that production is roughly equal to transmission plus distribution), and that GRI's estimate for production plus one-half of transmission is ~0.75 percent.

Cell: C470
Comment: Rick Heede:
Radian, cited in Delucchi, detailed estimate for US in 1992:
Production: 0.55 percent,
Transmission: 0.54 percent,
Distribution: 0.39 percent.
CMS uses production plus one-half of transmission emissions: 0.82 percent.

Cell: J470
Comment: Rick Heede:
EIA (2006) Annual Energy Review 2005, Table 6.1, US Dr Gas Production; Consumption totaled 21,981 Bcf (incl imports of 4,285 Bcf, balancing items, withdrawals, etc.)

Cell: C471
Comment: Rick Heede:
EPA and EIA, cited in Delucchi, detailed revision of EPA/GRI 1996:

Production: 0.52 percent,
Transmission: 0.54 percent,
Distribution: 0.38 percent.
CMS uses production plus one-half of transmission emissions: 0.79 percent.

Cell: C474
Comment: Rick Heede:
Sheppard (1982, base year 1975), cited in Kirchgessner (1997), global estimate for methane emissions from natural gas industry:
Global emissions of methane from gas industry: 50 Tg/yr,
Assumed loss rate: 2 percent (leakage) plus 25 percent for vented & flared.
Kirchgessner et al cite only industry-wide natural gas loss rates. CMS estimates (based on detailed US EPA profiles) that 56 to 72 percent of industry-wide emissions occur in production plus upstream transmission pipelines. CMS thus uses 64 percent of the estimates cited in Kirchgessner as applicable to the production of natural gas and upstream transmission.
The Sheppard estimate thus becomes: (2 percent + 0.5 percent) * 0.64 = 1.6 percent.

Cell: C475
Comment: Rick Heede:
Darmstadter, cited in Kirchgessner (1997), global estimate for methane emissions from natural gas industry:
Global emissions of methane from gas industry: 10 Tg/yr,
Assumed loss rate: 1 percent.
As above, CMS thus uses 64 percent of the estimates cited in Kirchgessner as applicable to the production of natural gas and upstream transmission.
The Darmstadter estimate thus becomes: 1.0 percent * 0.64 = 1.6 percent.

Cell: C476
Comment: Rick Heede:
Crutzen, cited in Kirchgessner (1997), global estimate for methane emissions from natural gas industry:
Global emissions of methane from gas industry: 33 Tg/yr,
Assumed loss rate: 4 percent.
As above, CMS thus uses 64 percent of the estimates cited in Kirchgessner as applicable to the production of natural gas and upstream transmission.
The Darmstadter estimate thus becomes: 4.0 percent * 0.64 = 2.56 percent.

Cell: C477
Comment: Rick Heede:
Cicerone & Oremland, cited in Kirchgessner (1997), global estimate for methane emissions from natural gas industry (early 1980s):
Global emissions of methane from gas industry: 25-50 Tg/yr,
Assumed loss rate: 2.5 percent (plus 14 Tg for vented and flared).
Since 1981 global gas production totaled 54.73 Tcf (which equals 1.044 billion tonnes or 1,044 Tg of natural gas), and 14 Tg/1044 Tg = 1.34 percent. CMS adds the methane from flaring and venting to the 2.5 percent above before applying the 64 percent factor (see note under Sheppard for details).
As above, CMS thus uses 64 percent of the estimates cited in Kirchgessner as applicable to the production of natural gas and upstream transmission.
The Cicerone & Oremland estimate thus becomes: (2.5 percent + 1.34) * 0.64 = 2.46 percent.

Cell: O477
Comment: Rick Heede:
EIA (2006) Table 18. Includes refinery emissions of 0.03 Mt CH4, exploration and production of 0.88 Mt CH4, and crude oil transportation of 0.01, total 0.92 Mt CH4.

Cell: C478
Comment: Rick Heede:
Barns & Edmonds, cited in Kirchgessner (1997), global estimate for methane emissions from natural gas industry (1986):
Global emissions of methane from gas industry: 40 Tg/yr,
Assumed loss rate: 0.5 percent in production (plus 16.2 Tg or 1.5 percent for vented plus transmission and distribution).
As above, CMS thus uses 64 percent of the estimates cited in Kirchgessner as applicable to the production of natural gas and upstream transmission.
The Barns & Edmonds estimate thus becomes: (0.5 percent + 1.5) * 0.64 = 1.28 percent.

Cell: J481
Comment: Rick Heede:
EIA (2006) Annual Energy Review 2005, Table 5.1, US Crude Oil Production totaled 5,121 million bbl per day (excluding NGL production of 1.71 million bbl per day); Consumption totaled 20.656 million bbl per day); Imports of 13.527 million bbl per day, exports 1.174 million bbl per day, net imports 12.353 million bbl per day).

Cell: D488
Comment: Rick Heede:
CMS note: This differs from percent of production in that flared natural gas is not counted in net natural gas production, the most common metric. In addition, CO2 is vented directly, removed from wet gas, and combusted from operators' production.

Cell: D496
Comment: Rick Heede:
Conversion from BP Statistical Yearbook, glossary.

Cell: F499
Comment: Rick Heede:
This conversion is specific to CMS accounts of non-fuel uses of natural gas, incomplete combustion, etc, although the CMS factor is very close to the carbon coefficient of natural gas used elsewhere.

Cell: C533
Comment: Rick Heede:
Stern & Kaufmann (1998), CDIAC's Trends, methodology paper, and we quote:
Flaring and Venting of Natural Gas: A ratio of 0.267 metric tons of CH4 per metric ton of CO2 released from flaring was assumed, for estimates from 1950 through 1994; that is, for each year t:

CH4t = 0.267Ft

where CH4 and F are metric tons of methane and carbon in carbon dioxide from flaring, respectively. The flaring data for this period are from Marland and Boden (1997).
For estimates back to 1860, the following formulae was used for each year t:

CH4t = 0.267(0.478-0.0002193t)Ot

where CH4 and O are metric tons of methane from flaring and carbon in carbon dioxide from oil consumption, respectively. The oil consumption data for this period are from Keeling (1994).
CMS has verified the calculations and converted the annual emissions into the equivalent rate (kgCH4 per tonne of CO2 emitted from consumption of produced crude oil & liquids). These rates decline moderately from 1870 to 1970, then decline more sharply thereafter. CMS List rates for 1880, 1920, 1960, 1980, and 2000 below. See the worksheets "CDIACglobalcarbon1751-2002.xls" and "CDIACmethane1860-1994.xls" for details.

Cell: C538
Comment: Rick Heede:
Stern & Kaufmann (1998) methane emissions estimates for ORNL's CDIAC Trends use a constant CH4 emissions rate: a non-variable factor of 1tCH4 per 0.0167 t of carbon emissions from gas consumption, which translates to a constant methane emissions rate of 4.5576 kg of CH4 per tonne of CO2 emissions arising from the consumption of natural gas. CMS uses a CO2/C factor of 3.664191, per WRI's CAIT database.

Cell: L638
Comment: Rick Heede:
2005 datum from US Energy Information Administration: Table: Dry Natural Gas Production. 1980-2000 and 2010-2025 from EPA (2006) Global Mitigation of Non-CO2 Greenhouse Gases.

Cell: K661
Comment: Rick Heede:
EIA Table: Production of Crude Oil, NGPL, and Other Liquids, 1980-2010.

Cell: K672
Comment: Rick Heede:
CMS did not correct 2010 oil production from the EPA 2010 forecast of 94.30 to the actual of 84.56 million bbls -- since methane emissions are driven, in part, by oil prod'n.

Cell: M695
Comment: Rick Heede:
EPA 2011, page 3-3: 3.1.1 Source Description: "CH4 is the principal component of natural gas (95 percent of pipeline quality natural gas) and is emitted from natural gas production, processing, transmission and distribution. Oil production and processing upstream of oil refineries can also emit CH4 in significant quantities since natural gas is often found in conjunction with petroleum deposits. In both oil and natural gas systems, CH4 is a fugitive emission from leaking equipment, system upsets, and deliberate flaring and venting at production fields, processing facilities, natural gas transmission lines and compressor stations, natural gas storage facilities, and natural gas distribution lines. Emissions calculations for this source utilize international statistics on production and consumption of natural gas and oil. Default emission factors relate emissions to energy product flows through different industry segments. Default emission factors differ between developed and developing countries. The emissions projections presented in this report rely on IPCC Tier 1 calculations and country reported inventory data."

Cell: L730
Comment: Rick Heede:
EPA (2012) Inventory of U.S. Emissions and Sinks 2010 (Final, Apr12), Table 3-46: Tier 2 Quantitative Uncertainty Estimates for CH4 Emissions from Petroleum Systems (TgCO2e and percent). Note (a): Range of 2010 relative uncertainty predicted by Monte Carlo Stochastic Simulation, based on 1995 base year activity factors, for a 95 percent confidence interval.

Cell: R760
Comment: Rick Heede:
CMS estimates the US methane leakage rate as a percent of US natural gas production 1990-2010, averages to 2.72 percent. This is compared to the estimate by Bradbury et al (WRI 2013) at 1.54 percent (this may be field production only).

Cell: R774
Comment: Rick Heede:
Comparison data: The U.S. EPA estimates that the methane leakage rate is approximately 1.54 per cent of total U.S. gas production (percentage calculated by the World Resources Institute (Bradbury et al., 2013) using data from EPA, 2012).

Cell: I777
Comment: Rick Heede:
Harvey, Susan (2012) Leaking Profits: The U.S. Oil and Gas Industry Can Reduce Pollution, Conserve Resources, and Make Money by Preventing Methane Waste, Natural Resources Defense Council, Harvey Consulting LLC, Mar12, 65 pp.