Worksheet on ancillary emissions of CO2 from flaring: oil and gas operations

Background calculations on ancillary emissions of methane and carbon dioxide

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30-Jul-13

Carbon Dioxide

IPCC Tier 1 methodology

IPCC Guidelines 2006: default values for CH4 and CO2 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

Natural Gas: fugitives, venting, & flaring

Table 1 — Listing and averaging emisssion factors from IPCC Guidelines 2006, vol 2, chapter 4: fugitive emissions, table 4.2.4 and 4.2.5

Gas factors are GgCO2/million m^3 of production, which equals kg CO2/m^3

Natural Gas	Fugitives Low kg CO2/m^3	Fugitives High kg CO2/m^3	Fugitives Average (or unitary) kg CO2/m^3	uncertainty estimates	Venting Low kg CO2/m^3	Venting High kg CO2/m^3	Venting Average (or unitary) kg CO2/m^3		Flaring Low kg CO2/m^3	Flaring High kg CO2/m^3	Flaring Average (or unitary) kg CO2/m^3	
Developed countries												
Production	0.000014	0.000082	0.000048	71%	na	na	na		na	na	0.001200	
Processing (default)	0.000012	0.000320	0.000166	93%	na	na	0.040000		na	na	0.003000	
Transmission & storage	na	na	0.000001		na	na	0.000003		na	na	na	
Condensate transport	na	na	0.000007		na	na	na		na	na	na	
Storage	na	na	0.000000		na	na	na		na	na	na	
Distribution	na	na	na		na	na	na		na	na	0.000051	not attributed
Total developed countries	0.000026	0.000402	0.000222				0.040003				0.004200	kg CO2/m^3
Developing countries												
Production	0.00001400	0.00018000							0.0012000	0.0016000		
Processing (default)	0.00001200	0.00002800	0.000020	40%	0.0400000	0.0950000	0.067500	41%	0.0030000	0.0041000	0.003550	15%
Transmission & storage	0.00000088	0.00000200			0.0000031	0.0000730	0.000038	92%	na	na	na	
Condensate transport	na	na	0.000007		na	na	na		na	na	0.000007	
Storage	na	na	na		na	na	na		0.0000001	0.0000003	0.000000	
Distribution	na	na	na		na	na	na		0.0000510	0.0001400	0.000096	not attributed
Total developing countries	0.000027	0.000210	0.000027		0.040003	0.095073	0.067538		0.004200	0.005700	0.003557	kg CO2/m^3
Average of Developed and Developing			**0.000093**	kg CO2/m^3			**0.053750**	kg CO2/m^3			**0.003275**	kg CO2/m^3

Table 2 — Calculation of fugitive CO2 rates

Natural Gas	Fugitives Average kg CO2/m^3		Venting Average kg CO2/m^3		Flaring Average kg CO2/m^3	
Average EF of Developed and Developing	0.000093	kg CO2/m^3	0.053750	kg CO2/m^3	0.003275	kg CO2/m^3
Fugitive, venting, and flaring from natural gas production, per m^3	0.000093	kg CO2/m^3	0.053750	kg CO2/m^3	0.003275	kg CO2/m^3
Emissions from combustion of 1 m^3 of natural gas	1.89	kg CO2/m^3	1.89	kg CO2/m^3	1.89	kg CO2/m^3
Emission rate	0.0049%	percent	Emission rate 2.8484%	percent	Emission rate 0.1736%	percent
	0.00005	t CO2 fug/tCO2 gas combustion	0.0285	t CO2 vented/tCO2 gas combustion	0.0017	t CO2 flared/tCO2 gas combustion
	0.05	**kg CO2 fug/tCO2 gas combustion**	**28.48**	kg CO2 vented/tCO2 gas combustion	**1.74**	kg CO2 flared/tCO2 gas combustion
			Fugitive + vented **28.53**	kg CO2/tCO2 comb.		

Table 3 — Summary of CO2 rates for natural gas

Source	kg CO2/t CO2	tCO2/Bcf
Fugitives	**0.049**	3
Venting	**28.484**	1,522
Flaring	**1.736**	93
Total	**30.269**	**1,617**
Fugitive + venting	**28.53**	1,525
Flaring	**1.736**	93
Total	**30.27**	1,617

Table 4 — 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
Coal	2.1289	MtCO2/Mt thermal coal		2,128.93	kg CO2/tonne

Linked to oil, gas, and coal EF worksheets

53,434 tCO2/Bcf

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

Carbon Dioxide

IPCC Tier 1 methodology

IPCC Guidelines 2006: default values for CH4 and CO2 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

Crude Oil: fugitives, venting, & flaring

Table 5 — Listing and averaging emisssion factors from IPCC Guidelines 2006, vol 2, chapter 4: fugitive emissions, table 4.2.4 and 4.2.5

Oil factors are GgCO2/10^3 m^3 of production, which equals t CO2/m^3

	Fugitives				Venting				Flaring			
	Low	High	Average		Low	High	Average		Low	High	Average	
	t CO2/m^3	t CO2/m^3	t CO2/m^3		t CO2/m^3	t CO2/m^3	t CO2/m^3		t CO2/m^3	t CO2/m^3	t CO2/m^3	
Developed countries												
Well drilling (flaring and venting)	na	na	na		na	na	0.0001000		na	na	na	
Well testing (flaring and venting)	na	na	na		na	na	0.0090000		na	na	na	
Well servicing (flaring and venting)	na	na	na		na	na	0.0000019		na	na	na	
Production	na	na	0.0002800		na	na	0.0018000		na	na	0.0340000	
Refining	na	na	0.0002800		na	na	0.0018000		ND	ND	ND	
Transport (pipelines)	na	na	0.0000005		ND	ND	ND		ND	ND	ND	
Transport (rail and truck)	na	na	0.0000023		ND	ND	ND		ND	ND	ND	
Transport (offshore tanker loading)	ND	ND	ND		ND	ND	ND		ND	ND	ND	
Refined product distribution	ND	ND	ND		ND	ND	ND		ND	ND	ND	not attributed
Total developed countries			0.0005628				0.0127019				0.0340000	t CO2/m^3
Developing countries												
Well drilling (flaring and venting)	na	na	na		na	na	na		na	na	na	
Well testing (flaring and venting)	na	na	na		na	na	na		na	na	na	
Well servicing (flaring and venting)	na	na	na	uncertainty estimate	na	na	na		na	na	na	
Production	0.0002800	0.0047000	0.0024900	89%	0.0018000	0.0025000	0.0021500	16%	0.0340000	0.0470000	0.0405000	16%
Refining	ND	ND	ND		ND	ND	ND		ND	ND	ND	
Transport (pipelines)	na	na	0.0000005		ND	ND	ND		ND	ND	ND	
Transport (rail and truck)	ND	ND	ND		na	na	0.0000023		ND	ND	ND	
Transport (offshore tanker loading)	ND	ND	ND		ND	ND	ND		ND	ND	ND	
Refined product distribution	ND	ND	ND		ND	ND	ND		ND	ND	ND	not attributed
Total developing countries	0.0002800	0.0047000	0.0024905		0.0018000	0.0025000	0.0021523		0.0340000	0.0470000	0.0405000	t CO2/m^3
Average of Developed and Developing			**0.001527**				**0.007427**				**0.037250**	t CO2/m^3
			1.53	kg CO2/m^3			7.43	kg CO2/m^3			37.25	kg CO2/m^3

Table 6 — Calculation of fugitive CO2 rates

Oil factors are GgCO2/10^3 m^3 of production, which equals t CO2/m^3

	Fugitives			Venting			Flaring		
	Average			Average			Average		
	t CO2/m^3			t CO2/m^3			t CO2/m^3		
Average EF of Developed and Developing	0.001527	t CO2/m^3		0.007427	t CO2/m^3		0.037250	t CO2/m^3	
Fugitive, venting, and flaring from oil production, per m^3	1.53	kg CO2/m^3		7.43	kg CO2/m^3		37.25	kg CO2/m^3	
Emissions from combustion of 1 m^3 of oil	2,336	kg CO2/m^3		2,336	kg CO2/m^3		2,336	kg CO2/m^3	
Emission rate	0.065%	percent	Emission rate	0.318%	percent	Emission rate	1.594%	percent	
	0.00065	t CO2 fug/tCO2 oil combustion		0.00318	t CO2 vented/tCO2 oil combustion		0.01594	t CO2 flared/tCO2 oil combustion	
Emission rate	**0.65**	kg CO2 fug/tCO2 oil combustion	**Emission rate**	**3.18**	kg CO2 vented/tCO2 oil combustion	**Emission rate**	**15.94**	kg CO2 flared/tCO2 oil combustion	
			Fugitive + vented	**3.83**	kg CO2/tCO2 comb.				

Table 7 — Summary of IPCC CO2 rates for crude oil

Source	kg CO2/t CO2	kg CO2/bbl
Fugitives	**0.65**	**0.24**
Venting	**3.18**	**1.18**
Flaring	**15.94**	**5.92**
Total	**19.78**	**7.35**
Fugitive + venting	**3.83**	**1.42**
Flaring	**15.94**	**5.92**
Total	**19.78**	**7.35**

IPCC values: (28Dec12) | Pre-IPCC values: (Dec12)

Table 8 — Final Oil & Natural Gas flaring and venting rates

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

Summary of Oil & Natural Gas Flaring and Venting rates

CO2: Flaring		CO2: Venting	CO2: Venting		
Flaring: Oil flaring: Oil kg CO2/tCO2	Flaring: Gas flaring: Gas kg CO2/tCO2	CO2 Venting: Oil (includes fugitives) kg CO2/tCO2	CO2 Venting: Gas (includes fugitives) kg CO2/tCO2		
15.94	**1.74**	**3.833**	**28.53**	oil total: 19.78	gas total: 30.27
				Sum:	50.05
linked to Table 7	linked to Table 3	linked to Table 7	linked to Table 3		
32.61	**3.26**	**0.429**	**23.34**	oil total: 33.04	gas total: 26.60
		fugitive + venting	fugitive + venting	Sum:	59.64
linked to Table 18 (World Bank flaring)	assumed 1/10th	Linked to Table 21 EPA: Oil vented CO2	linked to Table 20 EPA: Gas vented CO2		
Average of IPCC and other data: 24.28	2.50	2.13	25.93		

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		CO_2[1]		NMVOC		N_2O		Units of measure
				Value	Uncertainty (% of value)	Value	Uncertainty (% of Value)	Value	Uncertainty (% of value)	Value	Uncertainty (% of value)	
	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]	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]	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[a]	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		CO_2[1]		NMVOC		N_2O		Units of measure
				Value	Uncertainty (% of value)	Value	Uncertainty (% of Value)	Value	Uncertainty (% of value)	Value	Uncertainty (% of value)	
	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]	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]	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[a]	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		CO_2[1]		NMVOC		N_2O		Units of measure
				Value	Uncertainty (% of value)	Value	Uncertainty (% of Value)	Value	Uncertainty (% of value)	Value	Uncertainty (% of value)	
	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]	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]	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[a]	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		CO_2[1]		NMVOC		N_2O		Units of measure
				Value	Uncertainty (% of value)	Value	Uncertainty (% of Value)	Value	Uncertainty (% of value)	Value	Uncertainty (% of value)	
	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]	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]	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[a]	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

Other sources of carbon dioxide emissions rates, oil and natural gas

Table 9

World Bank Flaring estimates

	Billion cubic m/yr	Bcf /yr	MtCO2/yr
Global Flaring, 2004, "low"	117	4,132	221
Natural Gas prod'n 2004		50	3
Ratio of flared to produced gas		8262.88%	8262.88%
Global Flaring, circa 1998, "high"	135	4,768	255
Natural Gas prod'n 1998		-	-
Ratio of flared to produced gas		#DIV/0!	#DIV/0!

Table 10

Flaring CO2: CDIAC data 1950-2010

Flaring emissions, 1950-2010	-	MtC
Oil emissions, 1950-2010	-	MtC
Gas emissions, 1950-2010	1	MtC
Oil + Gas emissions	1	MtC
Flaring, percent of Oil	2.76%	
Flaring, percent of Gas	7.63%	
Flaring, percent of Oil + Gas	2.03%	

Table 11

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

Natural gas, EPA AP42 (1985)

1 lb =	23.80	cf
1 ton =	47,600	cf
1 tonne =	52,469	cf

Methane

	23.552	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

1 m^3 =	35.315	cubic feet

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

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

World Bank GGFR (2011) *9th Steering Committee Meeting*, Houston, May 30th 2008, page 2.

World Bank GGFR (2011) R*ussia, Kazakhstan Lead Way to Reduce Gas Flaring and Lower Emissions*, 27June2011;
Woman passing by a flare in Nigeria (Ed Kashi)

Table 12

Ancillary emissions of Carbon Dioxide from Flaring (oil & gas operations)

Carbon Dioxide

		Flaring emissions	Oil emissions	Gas emissions	Oil + Gas emissions	Total flaring percent of oil	Total flaring percent of gas	Total flaring % of oil + gas
		MtC	MtC	MtC	MtC	percent	percent	percent
CMS, ExxonMobil 1882-2002						1.70%	1.70%	
US GAO	World						3.00%	
World Bank flaring: low							8262.88%	
World Bank flaring: high							#DIV/0!	
CDIAC flaring	World, 1950	23.0	423	97	520	5.44%	23.71%	4.42%
CDIAC flaring	World, 1960	39.0	849	227	1,076	4.59%	17.18%	3.62%
CDIAC flaring	World, 1970	87.0	1,839	493	2,332	4.73%	17.65%	3.73%
CDIAC flaring	World, 1980	86.0	2,422	740	3,162	3.55%	11.62%	2.72%
CDIAC flaring	World, 1990	40.0	2,515	1,020	3,535	1.59%	3.92%	1.13%
CDIAC flaring	World, 2000	48.0	2,818	1,288	4,106	1.70%	3.73%	1.17%
CDIAC flaring	World, 2004	55.0	3,027	1,431	4,458	1.82%	3.84%	1.23%
CDIAC flaring	World 2007	68.0	3,074	1,551	4,625	2.21%	4.38%	1.47%
CDIAC flaring	World 2010	73.0	3,119	1,692	4,812	2.34%	4.31%	1.52%
CDIAC flaring	simple decadal average					3.35%	11.66%	2.58%
CDIAC flaring	**overall average, 1950-2004**					**2.76%**	7.63%	2.03%
CDIAC Flaring 1950-2010		**3,439**	**128,817**	**48,047**	**176,865**	**2.670%**	**7.16%**	**1.94%**

Table 12c CDIAC average flaring rate 1950-2010 26.70 kgCO2/tCO2

Table 12b

Using CDIAC average 1950-2010			
0.3714 tCO2/bbl combusted (linked)			
9.92 kgCO2/bbl			
	Oil 0.7	Gas 0.3	
	3.81%	7.11%	2.21%
	3.22%	5.15%	1.81%
	3.31%	5.29%	1.87%
	2.49%	3.49%	1.36%
	1.11%	1.18%	0.57%
	1.19%	1.12%	0.58%
	1.27%	1.15%	0.62%
	2.34%	3.50%	1.29%

Of the natural gas production quantified by CMS, 50 percent has been produced from 1990-2004.

Table 13

World Bank flaring estimates if attributed to both Oil & Gas operations

	All	If 70 % to Oil	If 30 % to Gas
	MtCO2/yr	MtCO2/yr	MtCO2/yr
Global Flaring, "low" (2004)	220.78	154.55	66.23
Oil emissions, 2004	Annual and cumulative Carbon Majors (MtC)		
Gas emissions, 2004	-		
Percent attributed to oil		**70.000%**	
Percent attributed to gas			**30.000%**
Global Flaring, "high" (2004)	255	178.32	76.42
Oil emissions, 2004	Annual and cumulative Carbon Majors (MtC)		
Gas emissions, 2004	-		
Percent attributed to oil		**70.000%**	
Percent attributed to gas			**30.000%**

Table 14

Venting note from XOM study	
	All to Gas Ops
Direct venting of CO2	**1.760%**

1 Bcf =	0.0534	MtCO2	(CMS worksheet on natural gas)

Table 15

EIA (2011) US Inventory 2009, Table 16	1990 MtCO2	2000 MtCO2	2009 MtCO2
CO2 in natural gas	14.00	18.30	21.22
Natural gas flaring	9.10	5.50	10.10
Dry gas production (Bcf), AER Table 6.1	17,810	19,182	20,580
CO2 vented (tCO2/Bcf)	786	954	1,031
CO2 flared (tCO2/Bcf)	511	287	491
CO2 from gas consumption (MtCO2)	1,025	1,241	1,218
CO2 vented (% of consumption)	1.37%	1.47%	1.74%
CO2 flared (% of consumption)	0.89%	0.44%	0.83%

Table 16

World Bank Flaring estimates

	Billion cubic m/yr	Bcf /yr	MtCO2	
Global Flaring 2004	135.0	4,767	255	CMS carbon factor for produced gas
Natural Gas prod'n 2004		-	-	Note: flared gas typically has lower heating value
Ratio of flared to produced gas				and 60-80% methane

Gervet, Bruno (2007) *Gas Flaring Emission Contributes to Global Warming*, Lulea University of Technology, Sweden, 14 pp.
"Gas flare in the Niger Delta," page 4.

U.S. Environmental Protection Agency (2012) Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 - 2010, 27Feb12, 471 pp.

Table 17 — **Carbon dioxide from venting at Natural Gas Systems & calculation of CO2 venting rates (USA)**

	US gas *production*	NatGas CO2		NatGas CO2	NatGas CH4	CO2 rate	CO2 rate	Vented of Prodn CO2
	Bcf	MtCO2		MtCO2e	MtCH4	tCO2/Bcf	kg CO2/t CO2	percent
	Table 2-4 and 2-5	CMS		EPA 2012 Table 3-4(	SAR 21xCO2			
1980	19,403	1,037						
1990	17,810	952		37.574		2,110	39.48	3.95%
1995	18,599	994		33.725	interpolated	1,813	33.93	3.39%
2000	19,182	1,025		29.876		1,558	29.15	2.91%
2005	18,051	965		30.316	interpolated	1,679	31.43	3.14%
2006	18,504	989		30.755		1,662	31.11	3.11%
2007	19,266	1,029		31.050		1,612	30.16	3.02%
2008	20,286	1,084		32.828		1,618	30.29	3.03%
2009	20,580	1,100		32.171		1,563	29.26	2.93%
2010	21,577	1,153		32.171		1,491	27.90	2.79%
	World gas consumption	Based on CMS EF				Average	31.41	
	Table 2-5	MtCO2/Bcf						
	~5 percent higher	0.0534						
1990-2020 totals	193,258	10,326		290.47				2.81%
			Weighted average of 1990 to 2010			1,678	28.13	

alternative source for Table 8, not applied
See Table 20.

1 cubic meter =	35.314667	cubic feet
1 Bcf =	0.05343 MtCO2	(CMS worksheet on natural gas)

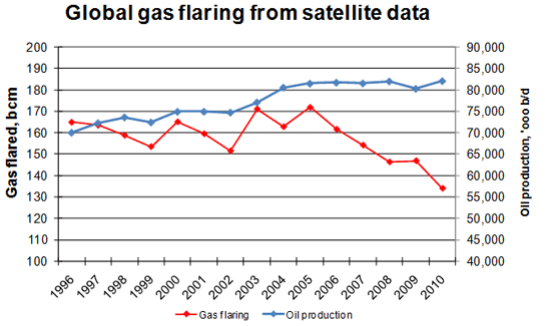
(CMS uses the natural gas emission factor, not a specifc factor for flared gas)

Estimated Flared Volumes from Satellite Data, 2006-2010

Estimated flared volume from satellite data

Volumes in bcm	2006	2007	2008	2009	2010	Change from 20098 to 2010
1 Russia	50.0	52.3	42.0	46.6	35.2	(11.4)
2 Nigeria	18.6	16.3	15.5	14.9	15.2	0.3
3 Iran	12.2	10.7	10.8	10.9	11.3	0.4
4 Iraq	7.2	6.7	7.1	8.1	9.1	1.1
5 Algeria	6.4	5.6	6.2	4.9	5.4	0.5
6 Angola	4.0	3.5	3.5	3.4	4.1	0.7
7 Kazakhstan	6.2	5.5	5.4	5.0	3.8	(1.2)
8 Libya	4.4	3.8	4.0	3.5	3.8	0.3
9 Saudi Arabia	4.2	4.2	4.3	3.9	3.7	(0.2)
10 Venezuela	2.1	2.2	2.7	2.8	2.8	0.0
11 Mexico	2.1	2.7	3.6	3.0	2.5	(0.5)
12 Indonesia	3.2	2.6	2.5	2.9	2.3	(0.6)
13 China	2.9	2.6	2.5	2.4	2.1	(0.3)
14 Canada	1.7	2.0	1.9	1.8	2.1	0.3
15 USA*	2.0	2.1	2.3	2.0	2.1	0.1
16 Uzbekistan	2.9	2.1	2.7	1.7	1.9	0.2
17 Qatar	2.3	2.4	2.3	2.2	1.9	(0.3)
18 Oman	2.3	2.0	2.0	1.9	1.8	(0.1)
19 Malaysia	1.9	1.8	1.9	1.9	1.5	(0.4)
20 Egypt	1.7	1.5	1.6	1.8	1.5	(0.3)
Total top 20	**138**	**133**	**125**	**126**	**114**	**(11.8)**
Rest of the world	23	21	22	21	20	(1.1)
Global flaring level	**162**	**154**	**146**	**147**	**134**	**(12.9)**

Source: NOAA Satellite data
*Coverage limited to Gulf of Mexico, Alaska, and partial continental USA



World Bank GGFR (2011) "Gas Flaring Down for Fifth Consecutive Year," *The News Flare*, issue 12, Mar-Oct11.

World Bank Global Gas Flaring Reduction: Gas flaring from gas associated with oil production

Estimated Flared Volumes from Satellite Data, 2006-2010
World Bank Global Gas Flaring Reduction
http://go.worldbank.org/D03ET1BVD0

Table 18

CDIAC global oil emissions, 2010: 8,550 MtCO2

linked to SumOil.xls

	2006 bcm	2007 bcm	2008 bcm	2009 bcm	2010 bcm	2010 Bcf	2010 ~MtCO2	2010 % of oil emissions	Percent of 2010
Russia	50.0	52.3	42.0	46.6	35.2	1,243	66	0.8%	26%
Nigeria	18.6	16.3	15.5	14.9	15.2	537	29	0.3%	11%
Iran	12.2	10.7	10.8	10.9	11.3	399	21	0.2%	8.4%
Iraq	7.2	6.7	7.1	8.1	9.1	321	17	0.2%	6.8%
Algeria		5.6	4.9	5.3	5.4	191	10	0.1%	4.0%
Angola		3.5	3.5	3.4	4.1	145	8	0.1%	3.1%
Kazakhstan		5.5	5.4	5.0	3.8	134	7	0.1%	2.8%
Libya		3.8	4.0	3.5	3.8	134	7	0.1%	2.8%
Saudi Arabia		3.9	3.9	3.6	3.7	131	7	0.1%	2.8%
Venezuela		2.2	2.7	2.8	2.8	99	5	0.1%	2.1%
Mexico		2.7	3.6	3.0	2.5	88	5	0.1%	1.9%
Indonesia		2.6	2.5	2.9	2.3	81	4	0.1%	1.7%
China		2.6	2.5	2.4	2.1	74	4	0.0%	1.6%
Canada		2.0	1.9	1.8	2.1	74	4	0.0%	1.6%
USA		2.2	2.4	3.3	2.1	74	4	0.0%	1.6%
Uzbekistan		2.1	2.7	1.7	1.9	67	4	0.0%	1.4%
Qatar		2.4	2.3	2.2	1.9	67	4	0.0%	1.4%
Oman		2.0	2.0	1.9	1.8	64	3	0.0%	1.3%
Malaysia		1.8	1.9	1.9	1.5	53	3	0.0%	1.1%
Egypt		1.5	1.6	1.8	1.5	53	3	0.0%	1.1%
Total Top 20	138.0	133.0	125.0	126.0	114.0	4,026	215	2.5%	85%
Rest of World		22.0	22.0	20.0	20.0	706	38	0.4%	15%
Global Flaring	**162.0**	**154.0**	**146.0**	**147.0**	**134.0**	**4,732**	**253**	**2.96%**	####
					(revised to 138 Bcm in 2012)				
Global flaring, MtCO	**305.7**	**290.6**	**275.5**	**277.4**	**252.9**				
Global flaring, MtC	**83.4**	**79.3**	**75.2**	**75.7**	**69.0**				

CMS note: compares well with CDIAC data (Table 30)

						Flared gas, Bcm	2006-2010 total	743.0
Global Oil emissions	8,606	8,631	8,726	8,478	8,550	MtCO2	2006-2010 total	42,992
Flared gas, Bcf	5,721	5,438	5,156	5,191	4,732		2006-2010 total	26,239
Flared emissions	305.7	290.6	275.5	277.4	252.9	MtCO2	2006-2010 total	1,402
Flaring rate	3.55%	3.37%	3.16%	3.27%	2.96%	kg CO2/tCO2		

	5,247.8	Bcf
	148.6	ave
Weighted average flaring rate	**3.26%**	percent
Weighted average flaring rate	**32.61**	kg CO2/tCO2
	linked to Table 8	

Using World Bank weighted average 2006-2010	
0.3714	tCO2/bbl combusted (linked)
12.11	kgCO2/bbl (from flaring)

Table 19

EIA data on vented CO2 from natural gas systems

U.S. Energy Information Administration (2011) *Emissions of Greenhouse Gases in the United States 2009*, U.S. DOE. www.eia.doe.gov

EIA Table 16: U.S. Carbon Dioxide Emissions from Other Sources, 1990-2009

(Million Metric Tons Carbon Dioxide)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
CO2 from Natural Gas Production	23.1	24.8	25.5	30.0	30.8	33.9	34.2	33.5	24.3	24.5
Carbon Dioxide in Nat. Gas	14.0	14.5	15.4	16.3	17.0	16.7	17.8	18.0	18.0	17.9
Gas Flaring	9.1	10.3	10.2	13.7	13.8	17.2	16.5	15.5	6.2	6.7
Emissions from Natural gas consumption (from EIA CO2 data Table 6)	1,024.6	1,046.9	1,082.2	1,109.5	1,134.3	1,183.7	1,205.5	1,211.3	1,188.8	1,192.0
Percent vented CO2 of consumption	**1.37%**	**1.39%**	**1.42%**	**1.47%**	**1.50%**	**1.41%**	**1.47%**	**1.49%**	**1.52%**	**1.50%**
U.S. natural gas production (dry), Bcf	17,810	17,698	17,840	18,095	18,821	18,599	18,854	18,902	19,024	18,832
Implied emissions (CMS emission factor)	951.7	945.7	953.3	966.9	1,005.7	993.8	1,007.4	1,010.0	1,016.5	1,006.3
Percent vented CO2 of production	**1.47%**	**1.54%**	**1.61%**	**1.68%**	**1.69%**	**1.68%**	**1.76%**	**1.79%**	**1.77%**	**1.78%**

Sum 2000-2009 166

average: 18,448

Sum 2000-2009 9,857

Average 1990-1999 **1.68%**

(Million Metric Tons Carbon Dioxide)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
CO2 from Natural Gas Production	23.8	24.7	24.4	24.5	24.3	25.3	26.6	28.2	30.6	31.3	na
Carbon Dioxide in Nat. Gas	18.3	18.9	18.4	18.6	18.4	18.1	18.7	19.5	20.5	21.2	na
Gas Flaring	5.5	5.9	6.0	5.9	5.8	7.2	7.8	8.7	10.1	10.1	na
Emissions from Natural gas consumption (from EIA CO2 data Table 6)	1,240.6	1,186.9	1,229.5	1,191.1	1,194.4	1,175.2	1,157.0	1,234.7	1,243.0	1,218.0	
Percent vented CO2 of consumption	**1.48%**	**1.59%**	**1.50%**	**1.56%**	**1.54%**	**1.54%**	**1.62%**	**1.58%**	**1.65%**	**1.74%**	
U.S. natural gas production (dry), Bcf	19,182	19,616	18,928	19,099	18,591	18,051	18,504	19,266	20,286	20,580	21,577
Implied emissions (CMS emission factor)	1,025.0	1,048.2	1,011.4	1,020.5	993.4	964.5	988.7	1,029.5	1,084.0	1,099.7	1,152.9
Percent vented CO2 of production	**1.79%**	**1.80%**	**1.82%**	**1.82%**	**1.86%**	**1.88%**	**1.90%**	**1.90%**	**1.90%**	**1.93%**	

Sum 2000-2009 191

Table 6: U.S. CO2 Emissions from Energy and Industry, 1990-2009
MtCO2

average: 19,210

Sum 2000-2009 10,265

Average 2000-2009 **1.86%**

Average 1990-2009 1.77%

Table 20

EPA data on vented CO2 from natural gas systems

Table A-135: CO2 Emission Estimates from the Natural Gas Processing Plants (Gg)

TgCO2 = MtCO2	1990	1992	1995	2000	2004	2005	2006	2007	2008	2009	2010
EPA 2010 Inventory Table A-135	MtCO2	MtCO2	MtCO2	MtCO2	MtCO2	MtCO2	MtCO2	MtCO2	MtCO2	MtCO2	MtCO2
CO2 from gas processing (AGR vents) (excludes NatGas transmission and distribution)	28.2	27.2 linked to Table 15 for source details	25.3	24.1	23.4 interpolated	22.8 interpolated	22.1	22.2 linked to Table 15 for source details	22.4	22.2	22.4
Implied emissions (U.S gas production)	951.7	953.3	993.8	1,025.0	993.4	964.5	988.7	1,029.5	1,084.0	1,099.7	1,152.9
Percent vented CO2 of production	**2.96%**	**2.85%**	**2.54%**	**2.35%**	**2.36%**	**2.36%**	**2.24%**	**2.15%**	**2.07%**	**2.02%**	**1.94%**

Sum 1990-2010 262

average 23.837

Sum 1990-2010 11,236

average 1,021

Average 1990-2010 2.33%

GRI/EPA default CO2 composition in natural gas production is 3.78 percent, vs average pipeline composition is 2 percent (but typically lower?).
See API Compendium 2009, Table E-4 at right.

See also API, page 5-29: average pipeline non-hydrocarbons at 2.81 percent, of which CO2 is 0.565 volume percent, or 1.59 percent CO2.

Weighted average 1990-2010 (kg CO2/tCO2) 23.34

source for Table 8

1 million bbl = 0.3714 MtCO2 (linked to SumOil.xls emission factor)

used in Table 14

Table 21

EPA data on vented CO2 from petroleum systems

TgCO2 = MtCO2	1990	1992	1995	2000	2004	2005	2006	2007	2008	2009	2010
EPA (2012) U.S. Inventory for 2010, Table A-144	EPA (2012) U.S. Inventory, Annex 3, Table A-144: Summary of CO2 Emissions from Petroleum Systems (Gg CO2) - converted to MtCO2.										
Vented CO2 from petroleum systems	0.394	0.377	0.360	0.344	0.331 interpolated	0.319 interpolated	0.306	0.310	0.297	0.325	0.327
U.S crude oil & lease condensate product million bbl / yr, EIA data	2,685	2,617	2,394	2,125	1,978	1,890	1,862	1,848	1,807	1,957	2,012
Implied emissions (U.S oil production)	997.2	972.2	889.3	789.2	734.6	702.0	691.7	686.6	671.1	726.7	747.3
Percent vented CO2 of production	**0.040%**	**0.039%**	**0.040%**	**0.044%**	**0.045%**	**0.045%**	**0.044%**	**0.045%**	**0.044%**	**0.045%**	**0.044%**

Sum 1990-2010 3.7

average 0.335

Sum 1990-2010 8,608

average 783

Average 1990-2010 0.043%

Weighted average 1990-2010 (kg CO2/tCO2) 0.429

source for Table 8

additional data on venting and flaring

EPA (2012) Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010

INGAA assumes 2 percent CO2 in natural gas

Interstate Natural Association of America (2005) Greenhouse Gas Emission Estimation Guidelines for Natural Gas Transmission and Storage, page 59.

EPA (2012) Draft U.S. Inventory 2010, chiefly tables A-134, A-135, and A-136.

Table 22 — **EPA data on vented and fugitive CO2 from natural gas & petroleum systems, U.S. 1990-2010**

Gg CO2 = thousand tCO2

	Natural gas							Petroleum	Total	Percent NatGas	Percent Petroleum			
	Natural gas production	Flaring included in Field Production (on-shore + off-shore)	Net non-flaring Field Production	Natural gas processing plants	Natural gas transmission and storage	Natural gas distribution	Total natural gas (Production, processing plants, transmission & storage, excluding flaring & distrib.)	Summary of CO2 emissions from Petroleum Systems	Sum of vented and fugitive CO2 from natural gas and petroleum systems			If EPA data on flaring (Table A-135) is allocated to petroleum (the primary source)	Emissions from combustion of US oil production (linked to Table 25)	Percent flaring from petroleum systems, calculated
EPA	MtCO2	MtCO2	MtCO2	MtCO2	MtCO2	MtCO2	MtCO2	MtCO2	MtCO2	percent	percent	MtCO2	MtCO2	percent
1990	9.703	9.324	**0.379**	**27.763**	**0.0618**	0.046	**28.204**	0.394	28.598	98.62%	1.40%	9.324	997	0.94%
1992	10.719	10.336	**0.383**	**26.706**	**0.0624**	0.045	**27.152**	0.377	27.529	98.63%	1.39%			
1995	17.941	17.365	**0.576**	**24.632**	**0.0637**	0.045	**25.272**	0.360	25.632	98.60%	1.42%	17.365	889	1.95%
2000	6.424	5.729	**0.695**	**23.343**	**0.0644**	0.044	**24.103**	0.344	24.447	98.59%	1.43%	5.729	789	0.73%
2006	8.801	7.959	**0.842**	**21.214**	**0.0633**	0.040	**22.119**	0.306	22.425	98.64%	1.38%	7.959	692	1.15%
2007	9.743	8.824	**0.918**	**21.199**	**0.0642**	0.041	**22.181**	0.310	22.491	98.62%	1.40%	8.824	687	1.29%
2008	11.319	10.385	**0.934**	**21.385**	**0.0651**	0.042	**22.384**	0.297	22.681	98.69%	1.33%	10.385	671	1.55%
2009	10.871	9.905	**0.966**	**21.188**	**0.0650**	0.041	**22.219**	0.325	22.544	98.56%	1.46%	9.905	727	1.36%
2010	10.844	9.905	**0.939**	**21.346**	**0.0654**	0.041	**22.351**	0.327	22.678	98.56%	1.46%	9.905	747	1.33%
Total 1990-2010	**96.366**	**89.733**	**6.633**	**208.776**	**0.575**	**0.385**	**215.985**	**3.040**	**219.025**	**98.61%**	**1.39%**	79.397	6,199	1.28%
average	10.707	9.970	0.737	23.197	0.064	0.043	23.998	0.34	24.34			9.925	775	1.28%
percent of total	44.6%	41.5%	3.1%	96.7%	0.3%	0.2%	100.0%							kg CO2/tCO2
													Converted to rate	**12.81**

not linked to Table 8

Table 23 — **Venting rates from Natural Gas Systems, US 1990-2010**

	Vented CO2: NatGas		Estimated CO2 emissions from US Gas Production		Vented CO2 rate, natural gas
EPA	MtCO2		MtCO2		kg CO2/tCO2
1990	28.204		952		29.637
1992	27.152		953		28.483
1995	25.272		994		25.429
2000	24.103		1,025		23.516
2004	23.441		993		23.598
2005	22.780		965		23.618
2006	22.119		989		22.371
2007	22.181		1,029		21.547
2008	22.384		1,084		20.650
2009	22.219		1,100		20.205
2010	22.351		1,153		19.386
Total	**262.206**		**11,236**		**23.336**

Vented CO2: kg CO2/tCO2 from natural gas production

Table 24 — **Venting rates from Petroleum Systems, US 1990-2010**

	Vented CO2: Petroleum		Est. CO2 from US Oil & NGL production		Vented CO2 rate, petroleum
EPA	MtCO2		MtCO2		kg CO2/tCO2
1990	0.394		997		0.395
1992	0.377		972		0.388
1995	0.360		889		0.405
2000	0.344		789		0.436
2004	0.331		735		0.451
2005	0.319		702		0.454
2006	0.306		692		0.442
2007	0.310		687		0.452
2008	0.297		671		0.443
2009	0.325		727		0.447
2010	0.327		747		0.438
Total	**3.690**		**8,608**		**0.429**

Vented CO2: kg CO2/tCO2 from liquids production

CMS factor for oil & NGL emissions: 0.3714 tCO2 per bbl

linked to SumOil.xls

Table 25b

Using CDIAC average 1950-2010	
0.3714	tCO2/bbl combusted (linked)
0.16	kgCO2/bbl (Vented from petroleum)

Table 26 was added 18 July 2012

Source: data in table A-134 appear to be gas flaring at (chiefly) oil production, onshore and offshore.

EPA (2012) Draft U.S. Inventory 2010, Tables A-134: CO2 Emission Estimates from the Natural Gas Production Stage (Gg), converted to MtCO2.

Table 25 — **Venting rates from Petroleum Systems, US 1990-2010**

Gg = million kg CO2

	Oil production	Vented CO2	Vented CO2 rate	Emissions US prod	Vented CO2 rate
	million bbl	million kg CO2	kg CO2/bbl	MtCO2	kg CO2/tCO2
	Crude & NGPLs	EPA Table A-144	calculated	calculated	calculated
1990	2,685	394	0.15	997	0.395
1995	2,394	360	0.15	889	0.405
2000	2,125	344	0.16	789	0.436
2006	1,862	306	0.16	692	0.442
2007	1,848	310	0.17	687	0.452
2008	1,807	297	0.16	671	0.443
2009	1,957	325	0.17	727	0.447
2010	2,012	337	0.17	747	0.451
Average	**2,086**	**334**	**0.16**	**775**	**0.434**
	EIA data	EPA data			
Totals	16,690	2,673		6,199	
	Weighted average		**0.160**	**775**	**0.431** kg CO2/tCO2

Table 26 — **Flaring rates from Natural Gas Systems, US 1990-2010**

	Flaring		CO2 US Gas Prodn		NatGas flaring rate
EPA	MtCO2		MtCO2		kg CO2/tCO2
1990	9.324		952		9.80
1992	10.336		953		10.84
1995	17.365		994		17.47
2000	5.729		1,025		5.59
2006	7.959		989		8.05
2007	8.824		1,029		8.57
2008	10.385		1,084		9.58
2009	9.905		1,100		9.01
2010	9.905		1,153		8.59
Total	89.733		**9,278**		**87.504**
average (9 yrs)	9.970		1,031		9.72 kgCO2/tCO2

Flared CO2: kg CO2/tCO2 from natural gas production

Source for Table 13, and linked to Table 15.

Table A-135: CO_2 Emission Estimates from the Natural Gas Processing Plants (Gg)

Activity	1990	1992	1995	2000	2006	2007	2008	2009	2010
Normal Fugitives									
Plants – Before CO_2 removal	2.56	2.46	2.27	1.97	1.92	1.93	1.94	1.95	1.97
Plants – After CO_2 removal	0.57	0.55	0.50	0.44	0.43	0.43	0.43	0.43	0.44
Reciprocating Compressors – Before CO_2 removal	19.67	19.66	20.49	21.16	20.41	21.28	22.33	22.81	23.96
Reciprocating Compressors – After CO_2 removal	4.37	4.36	4.55	4.70	4.53	4.72	4.96	5.06	5.32
Centrifugal Compressors (wet seals) – Before CO_2 removal	14.55	14.54	15.05	15.21	13.92	13.98	14.06	14.09	14.18
Centrifugal Compressors (wet seals) – After CO_2 removal	3.23	3.23	3.34	3.38	3.09	3.10	3.12	3.13	3.15
Centrifugal Compressors (dry seals) – Before CO_2 removal	0	0	0.05	0.21	0.58	0.86	1.20	1.36	1.73
Centrifugal Compressors (dry seals) – After CO_2 removal	0	0	0.01	0.05	0.13	0.19	0.27	0.30	0.38
Vented and Combusted									
Normal Operations									
Compressor Exhaust									
Gas Engines[1]	NE	NE	NE	NE	NE	NE	NE	NE	NE
Gas Turbines[1]	NE	NE	NE	NE	NE	NE	NE	NE	NE
AGR Vents	27,708.20	26,652.30	24,577.92	23,288.24	21,160.97	21,144.38	21,328.16	21,130.48	21,286.71
Kimray Pumps	0.39	0.39	0.41	0.42	0.41	0.43	0.45	0.46	0.48
Dehydrator Vents	2.42	2.42	2.52	2.61	2.51	2.62	2.75	2.81	2.95
Pneumatic Devices	0.29	0.27	0.25	0.22	0.21	0.22	0.22	0.22	0.22
Routine Maintenance									
Blowdowns/Venting	6.36	6.12	5.64	4.89	4.78	4.80	4.83	4.84	4.89
Total	**27,762.60**	**26,706.31**	**24,632.01**	**23,343.49**	**21,213.87**	**21,198.94**	**21,384.71**	**21,187.94**	**21,346.38**

[1] Energy use CO_2 emissions not estimated to avoid double counting. NE = not estimated.

EPA (2012) Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010
Annex 3, section 3.4, Table A-135: CO2 Emission Estimates from the Natural Gas Processing Plants (Gg)

Table 3-40: Non-combustion CO_2 Emissions from Natural Gas Systems (Gg)

Stage	1990	2000	2006	2007	2008	2009	2010
Field Production	9,703	6,424	8,801	9,743	11,319	10,871	10,844
Processing	27,763	23,343	21,214	21,199	21,385	21,188	21,346
Transmission and Storage	62	64	63	64	65	65	65
Distribution	46	44	40	41	42	41	41
Total	**37,574**	**29,876**	**30,755**	**31,050**	**32,828**	**32,171**	**32,171**

Note: Totals may not sum due to independent rounding.

EPA (2012) Draft U.S. Inventory, Table 3-40, page 3-48.
EPA Methodology note
See Annex 3.4.

Table A-144: Summary of CO_2 Emissions from Petroleum Systems (Gg)

Activity	1990	1995	2000	2006	2007	2008	2009	2010
Production Field Operations	**376**	**341**	**323**	**285**	**292**	**280**	**311**	**322**
Pneumatic device venting	27	26	24	22	22	23	23	23
Tank venting	328	296	281	246	252	239	270	281
Misc. venting & fugitives	18	18	17	16	16	16	16	16
Wellhead fugitives	1	1	1	1	1	1	1	1
Refining								
Asphalt Blowing	18	19	21	20	18	17	14	15
Total	**394**	**360**	**344**	**306**	**310**	**297**	**325**	**337**

EPA (2012) Draft Inventory of U.S. Emissions and Sinks 2010, Annex 3: Methodological Descriptions for Additional Source or Sink Categories, Table A-144: Summary of CO2 Emissions from Petroleum Systems (Gg)

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

CO2 emissions from production stage are NOT included in Tables 13 and 15.

Table A-134: CO_2 Emission Estimates from the Natural Gas Production Stage (Gg)

Activity	1990	1992	1995	2000	2006	2007	2008	2009	2010
Normal Fugitives									
Gas Wells									
Non-Associated Gas Wells	2.92	3.00	3.61	5.72	5.24	4.82	6.22	6.84	6.10
Gas Wells with Hydraulic Fracturing	0.00	0.00	0.00	0.03	0.13	0.15	0.15	0.14	0.14
Field Separation Equipment									
Heaters	1.86	1.91	2.32	3.95	4.61	4.48	5.53	5.93	5.43
Separators	6.04	5.97	7.17	11.29	13.20	13.16	15.76	16.80	15.63
Dehydrators	1.50	1.54	1.73	2.58	2.94	2.93	3.38	3.60	3.42
Meter/ Piping	5.85	5.85	6.95	10.90	12.69	12.57	15.12	16.12	14.96
Gathering Compressors									
Small Reciprocating Comp.	2.95	2.98	3.57	5.46	6.41	6.38	7.63	8.14	7.57
Large Reciprocating Comp.	0.69	0.91	1.02	1.33	1.40	1.40	1.62	1.62	1.68
Large Reciprocating Stations	0.05	0.06	0.07	0.09	0.09	0.09	0.11	0.11	0.11
Pipeline Leaks	10.75	10.85	11.99	16.04	18.21	18.25	20.78	21.92	20.86
Vented and Combusted									
Drilling and Well Completion									
Gas Well Completions without Hydraulic Fracturing[2]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gas Well Completions with Hydraulic Fracturing	2.18	1.59	5.26	45.15	111.95	164.18	93.34	82.71	82.71
Well Drilling	0.07	0.05	0.05	0.12	0.21	0.20	0.21	0.12	0.12
Produced Water from Coal Bed Methane Wells									
Powder River[1]	NE	NE	NE	NE	NE	NE	NE	NE	NE
Black Warrior[1]	NE	NE	NE	NE	NE	NE	NE	NE	NE
Normal Operations									
Pneumatic Device Vents	58.49	60.24	69.38	101.86	119.29	118.75	139.61	148.96	139.96
Chemical Injection Pumps	2.95	3.11	3.75	6.33	7.45	7.20	8.91	9.58	8.75
Kimray Pumps	13.41	13.71	15.43	22.91	26.12	26.05	30.00	31.95	30.40
Dehydrator Vents	4.18	4.28	4.81	7.14	8.15	8.12	9.35	9.96	9.48
Condensate Tank Vents									
Condensate Tanks without Control Device	10.25	9.43	8.79	9.34	11.26	11.17	11.90	11.62	11.62
Condensate Tanks with Control Device	2.05	1.89	1.76	1.87	2.25	2.23	2.38	2.32	2.32
Compressor Exhaust Vented									
Gas Engines[1]	NE	NE	NE	NE	NE	NE	NE	NE	NE
Well Workovers									
Gas Wells without Hydraulic Fracturing	0.06	0.06	0.06	0.08	0.10	0.10	0.11	0.12	0.11
Gas Wells with Hydraulic Fracturing	0.47	0.85	2.36	22.92	119.63	136.05	145.38	143.97	143.97
Well Clean Ups (LP Gas Wells)	251.41	252.88	273.66	339.55	367.46	376.97	413.68	440.06	430.62
Blowdowns									
Vessel BD	0.04	0.04	0.04	0.06	0.07	0.07	0.08	0.08	0.08
Pipeline BD	0.17	0.17	0.19	0.26	0.29	0.29	0.33	0.35	0.33
Compressor BD	0.11	0.12	0.14	0.21	0.25	0.25	0.29	0.31	0.29
Compressor Starts	0.25	0.26	0.31	0.47	0.55	0.55	0.66	0.70	0.65
Upsets									
Pressure Relief Valves	0.03	0.03	0.04	0.05	0.06	0.06	0.07	0.07	0.07
Activity	**1990**	**1992**	**1995**	**2000**	**2006**	**2007**	**2008**	**2009**	**2010**
Mishaps	0.09	0.09	0.10	0.14	0.16	0.16	0.18	0.19	0.18
Flaring Emissions - Onshore	9,092.72	10,172.49	17,167.79	5,525.04	7,812.35	8,664.25	10,024.82	9,545.39	9,545.39
Offshore									
Offshore water Gas Platforms (GoM & Pacific)	1.47	1.51	1.56	1.64	1.63	1.55	1.52	1.41	1.35
Deepwater Gas Platforms (GoM & Pacific)	0.03	0.03	0.04	0.07	0.12	0.11	0.11	0.11	0.12
Flaring Emissions - Offshore	230.37	163.13	197.22	204.31	146.48	160.05	360.00	360.00	360.00
Total	**9,703.42**	**10,719.03**	**17,941.16**	**6,424.06**	**8,800.75**	**9,742.58**	**11,319.22**	**10,871.21**	**10.844.43**

[1] Energy use CO_2 emissions not estimated to avoid double counting. NE = not estimated.
[2] Emissions are not actually 0, but too small to show at this level of precision.
Note: Totals may not sum due to independent rounding.

EPA (2012) Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010
Annex 3, section 3.4, Table A-134: CO2 Emission Estimates from the Natural Gas Production Stage (Gg)

additional data on venting and flaring

Farina, Michael F. (2011) Flare Gas Reduction: Recent global trends and policy considerations, GE Energy Global Strategy and Planning, Jan11, 60 pp.

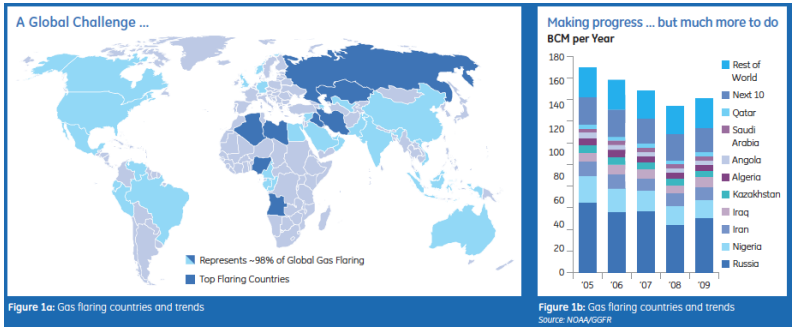


Figure 1a: Gas flaring countries and trends

Figure 1b: Gas flaring countries and trends
Source: NOAA/GGFR

Farina, Michael F. (2011) page 7.

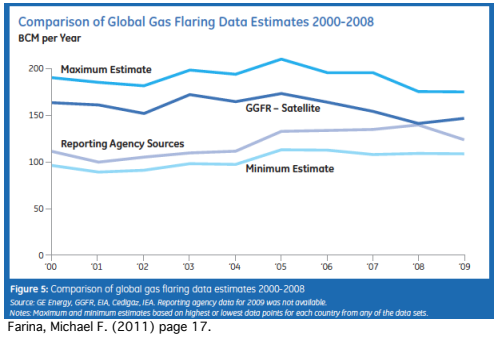


Figure 5: Comparison of global gas flaring data estimates 2000-2008
Source: GE Energy, GGFR, EIA, Cedigaz, IEA. Reporting agency data for 2009 was not available.
Notes: Maximum and minimum estimates based on highest or lowest data points for each country from any of the data sets.

Farina, Michael F. (2011) page 17.
CMS note: Estimates are of associated gas (AG) and fugitive emissions, and exclude significant refinery off-gas, petrochemical off-gas, and natural gas operations

Gas Flaring GGFR – Satellite
BCM per Year

Region	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09
World	165	162	153	174	167	175	165	155	142	149
Russia	40.6	41.9	44.5	53.4	50.6	59.0	50.6	52.0	40.6	46.1
Caspian	6.6	7.3	10.0	10.0	9.8	10.5	10.8	9.0	9.8	8.2
Africa	50.0	48.8	40.4	44.9	43.3	41.7	39.0	33.9	31.8	31.9
Middle East	38.6	35.5	33.2	39.6	38.4	38.7	39.4	36.1	34.4	36.1
L. America	10.4	9.6	8.2	8.0	7.5	8.0	7.6	7.9	9.0	9.5
SE Asia	8.2	8.3	7.0	7.4	7.2	7.0	7.4	6.6	7.0	7.1
North Asia	2.3	2.4	2.3	2.7	2.8	2.9	2.9	2.6	2.3	2.4
N. America	4.2	4.2	3.8	4.1	3.4	3.5.	3.7	3.9	4.1	3.9
Europe	4.6	4.4	4.1	4.2	4.0	3.8	3.7	3.3	3.1	3.2

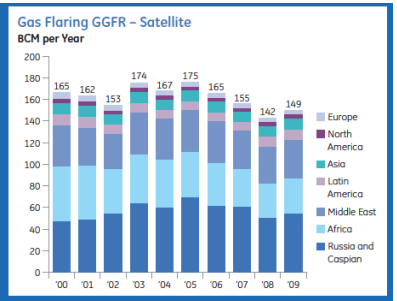


Figure 6.1: Regional gas flaring trends 2000 to 2009 from two data sources
Source: GE Energy, GGFR/NOAA, EIA, Cedigaz, IEA.

Farina, Michael F. (2011) page 18.

Oil Production by Region
Million Barrels per Day

Region	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09
World	74.9	74.8	74.4	77.0	80.3	81.1	81.5	81.4	81.8	79.9
Russia	6.5	7.1	7.7	8.5	9.3	9.6	9.8.	10.0	9.9	10.0
Caspian	1.3	1.5	1.7	1.8	2.0	2.1	2.4	2.7	2.8	3.0
Africa	7.8	7.9	8.0	8.4	9.3	9.8	10.0	10.3	10.3	9.7
Middle East	23.5	23.0	21.6	23.4	24.8	25.3	25.5	25.2	26.2	24.4
L. America	10.3	10.3	10.2	10.1	10.5	0.7	10.5	10.1	9.8	9.7
SE Asia	4.6	4.5	4.5	4.3	4.3	4.2	4.1	4.1	4.1	4.2
North Asia	3.3	3.3	3.3	3.4	3.5	3.6	3.7	3.7	3.8	3.8
N. America	10.5	10.3	10.5	10.4	10.3	9.9.	10.0	10.2	10.0	10.4
Europe	7.1	6.9	6.9	6.6	6.3	5.9	5.4	5.2	4.9	4.6

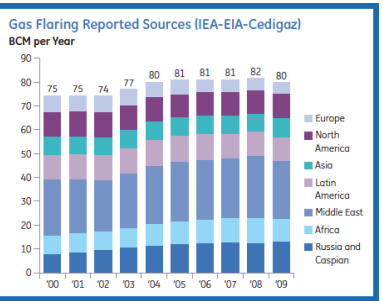


Figure 8: Crude oil production by region
Source: BP Statistical Review of World Energy, June 2010

Farina, Michael F. (2011) page 21.

	CO_2 Emissions from Gas Flaring					Flaring Share of Energy Sector CO_2 Emissions				
	Million Metric Tonnes per Year					Percentage				
Region	'04	'05	'06	'07	'08	'04	'05	'06	'07	'08
World	424	445	419	394	361	1.5	1.5	1.4	1.3	1.2
Russia	129	150	129	132	103	7.3	8.4	7.1	7.4	5.6
Caspian	25	27	27	23	25	5.9	6.2	6.1	5.2	5.3
Africa	110	106	99	86	81	10.3	9.8	9.1	7.8	7.3
Middle East	98	98	100	92	87	7.0	6.6	6.5	5.7	5.1
L. America	19	20	19	20	23	1.3	1.3	1.2	1.2	1.4
SE Asia	18	18	19	17	18	0.7	0.6	0.6	0.5	0.5
North Asia	7	7	7	7	6	0.1	0.1	0.1	0.1	0.1
N. America	9	9	9	10	11	0.1	0.1	0.1	0.1	0.2
Europe	10	10	9	8	8	0.2	0.2	0.2	0.2	0.2

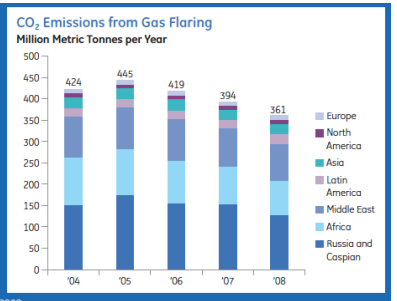


Figure 9: CO2 emissions from gas flaring and share of energy sector emissions: 2004-2008
Sources: GGFR/NOAA, EIA
Notes: Energy Sector includes CO2 from coal, oil, gas, and Gas Flaring includes calculated CO2 from flaring and estimated venting at flare sites.

Farina, Michael F. (2011) page 23.
Farina, page 21: "Based on the flaring estimates presented above, 350 to 400 million metric tons (MMT) of CO2 equivalent comes from associated gas flaring and venting of methane at flare sites. This represents about 1.2 percent of global CO2 emissions from primary hydrocarbon sources (coal, oil, and gas). Based on the 2008 data, the 361 MMT of CO2 emissions coming from gas flaring is roughly equal to 44,000 MW of electricity or roughly 62 medium-sized 700 MW coal plants. Put another way, assuming that 1.0 million average cars and trucks produce 4.6 million tons of CO2 equivalent per year, eliminating gas flaring would be equivalent to taking 77 million cars off the road annually."

Nigerian Gas Flaring by Company 2000-2009
Billion Cubic Meters per Year

Company	'00-'03	'03-'05	'06	'07	'08	'09
Grand Total	24.8	25.7	23.0	19.0	17.8	14.9
Shell (SPDC)	7.9	7.1	4.6	2.7	2.8	2.1
ExxonMobil	3.6	5.1	5.7	5.3	3.8	4.1
Chevron	5.1	4.0	5.6	4.7	4.6	3.4
Total	1.2	2.5	1.8	1.0	1.0	1.0
ENI (NAOC)	5.5	4.7	3.1	3.1	2.7	2.1
Addax-Sinopec	0.8	0.9	1.3	1.7	2.1	1.6
Others	0.7	1.4	0.8	0.6	0.8	0.5

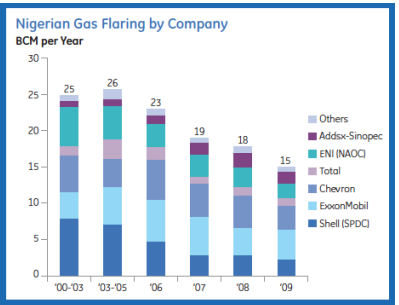


Figure 12: Nigerian Gas Flaring by company 2000-2008
Source: Nigerian National Petroleum Corporation (NNPC) statistical bulletins

Farina, Michael F. (2011) page 27.

additional data on venting and flaring

Farina, Michael F. (2011) Flare Gas Reduction: Recent global trends and policy considerations, GE Energy Global Strategy and Planning, Jan11, 60 pp.

Gas Flaring in Latin America and North America

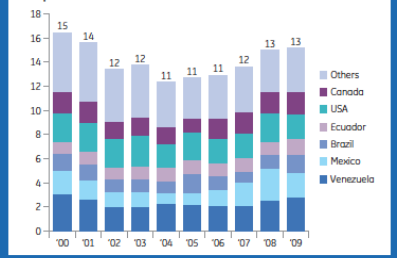
BCM per Year

Region	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09
Americas	14.6	13.8	12.0	12.2	10.9	11.5	11.2	11.7	13.1	13.4
Venezuela	3.1	2.6	2.0	2.0	2.2	2.2	2.1	2.2	2.6	2.8
Mexico	1.9	1.6	1.2	1.3	0.9	1.0	1.2	1.8	2.6	2.0
Brazil	1.5	1.3	1.1	1.0	1.0	1.6	1.2	1.0	1.1	1.6
Ecuador	1.0	1.1	1.0	1.0	1.1	1.1	1.1	1.1	1.1	1.3
USA	2.3	2.4	2.3	2.6	2.0	2.2	2.0	2.0	2.3	2.0
Canada	1.9	1.8	1.4	1.6	1.4	1.3	1.6	1.8	1.8	1.8
Columbia	0.7	0.8	0.8	0.6	0.5	0.4	0.4	0.4	0.4	0.5
Argentina	1.3	1.3	1.3	1.2	1.1	1.0	0.9	0.9	0.8	1.0
Others	1.1	1.0	0.9	0.9	0.7	0.7	0.6	0.5	0.5	0.4

Figure 16: Gas flaring in the Americas
Source: GGFR/NOAA

Gas Flaring in the Americas

BCM per Year



Farina, Michael F. (2011) page 36.

Gas Flaring in Asia

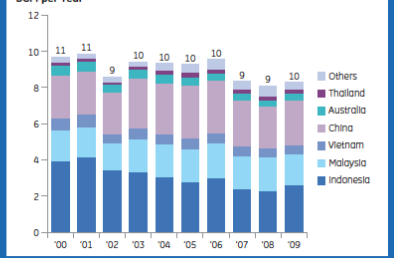
BCM per Year

Region	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09
Asia	10.5	10.7	9.3	10.1	10.0	9.9	10.4	9.2	9.3	9.5
Indonesia	4.0	4.2	3.5	3.4	3.1	2.9	3.1	2.5	2.3	2.7
Malaysia	1.6	1.6	1.4	1.8	1.7	1.8	1.9	1.8	1.9	1.7
Vietnam	0.7	0.7	0.5	0.6	0.6	0.6	0.5	0.6	0.5	0.6
China	2.3	2.4	2.3	2.7	2.8	2.9	2.9	2.6	2.3	2.4
Australia	0.6	0.5	0.4	0.5	0.5	0.4	0.4	0.4	0.4	0.4
Thailand	0.1	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
India	0.6	0.6	0.5	0.6	0.5	0.5	0.6	0.7	0.8	1.0
Brunei Darus	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.4	0.2
Others	0.3	0.3	0.3	0.2	0.4	0.5	0.5	0.5	0.6	0.3

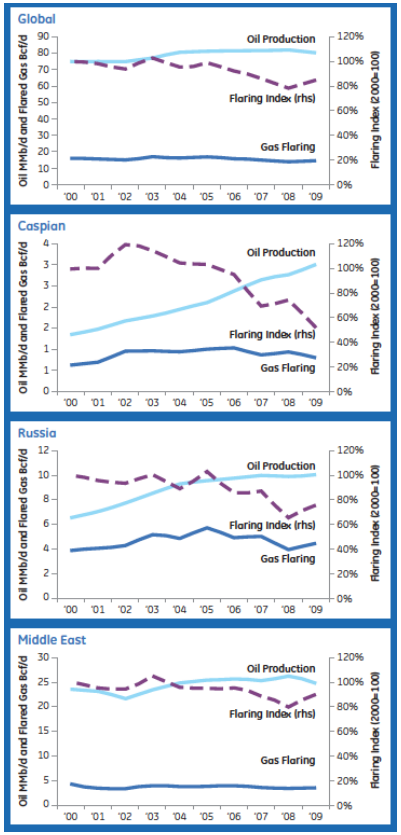
Figure 17: Gas flaring in Asia
Source: GGFR/NOAA

Gas Flaring in Asia

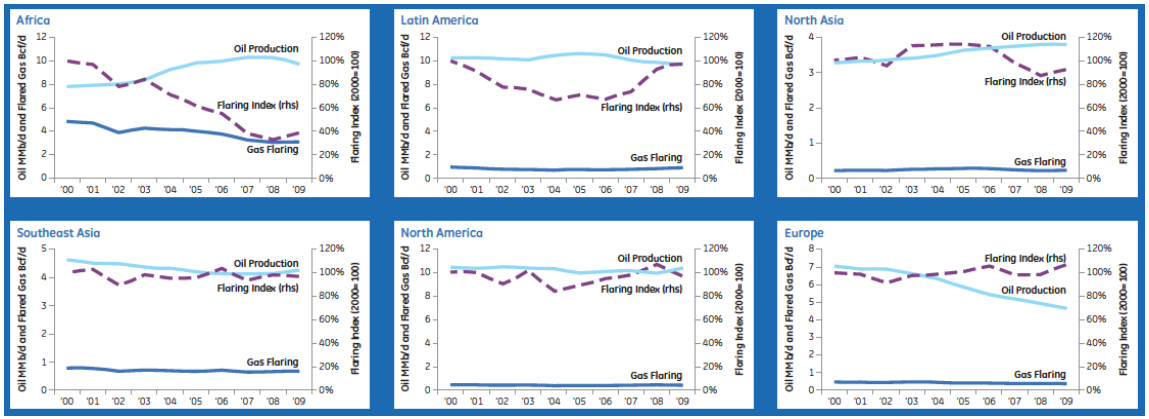
BCM per Year



Farina, Michael F. (2011) page 36.



Farina, Michael F. (2011) page 20.



Farina, Michael F. (2011) page 20.
"On an energy equivalent basis, globally 150 Bcm of annual gas flaring is the same as almost 2.4 MMB/d of oil production 3 percent of global crude production."

Farina, Michael F. (2011) page 42.

Figure 7.1: Regional gas flaring relative to crude oil production Source: GGFR/NOAA, BP Statistical Report, GE Energy.

additional data on venting and flaring

Farina, Michael F. (2011) Flare Gas Reduction: Recent global trends and policy considerations, GE Energy Global Strategy and Planning, Jan11, 60 pp.

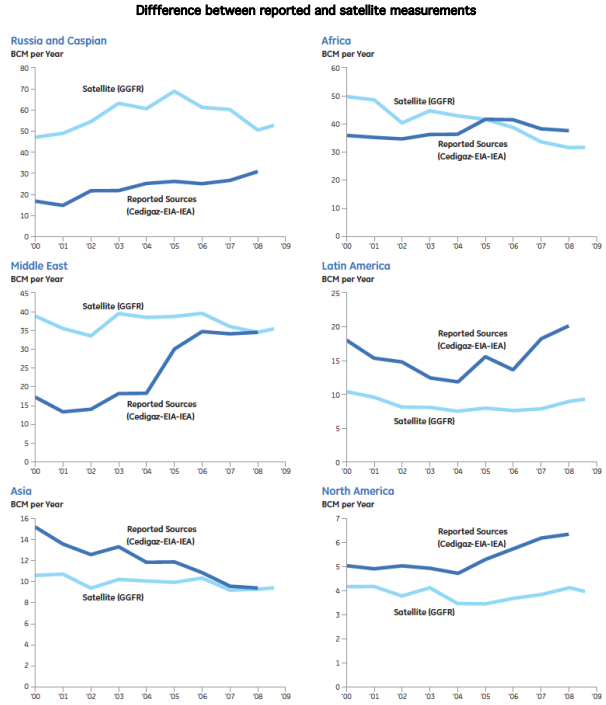
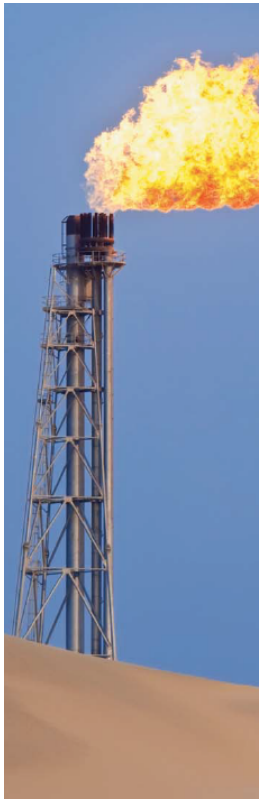


Figure A-1. A comparison of regional flaring data shows the dramatic differences between the reported levels of gas flaring and the levels indicated by satellite survey.
Note: European estimates are broadly consistent.
Source: GE Energy, GGFR, EIA, Cedigaz, IEA.

Farina, Michael F. (2011) page 50.

Farina (2011) page 57.

Farina, Michael F. (2011) page 29.
The "Eternal" flames of Ebocha (Nigeria); Michael Kamber, 2005



Farina, Michael F. (2011) page 34.

Farina (2011) page 58.

additional data on venting and flaring

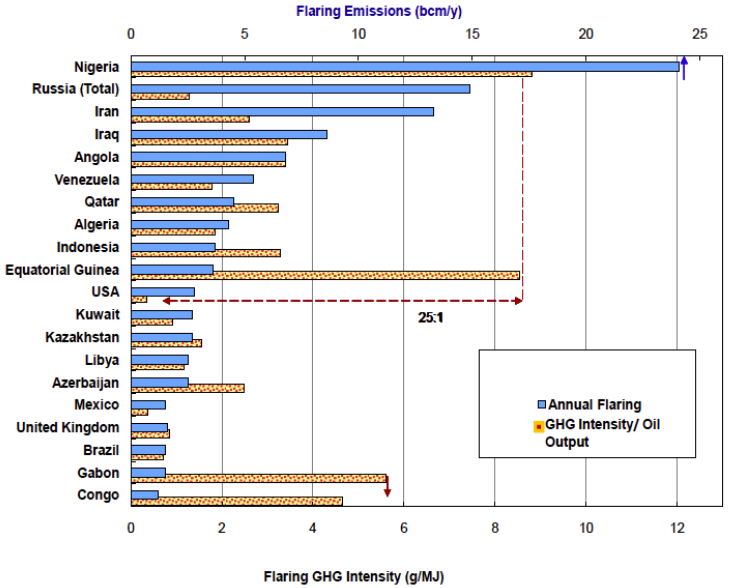
Life Cycle Associates (2009) Assessment of Direct and Indirect GHG Emissions Associated with Petroleum Fuels

	Country	Flaring (bcm/y)	Production (1000 bbl/d)	U.S. Consumption	Flared m3/bbl	g/gal Crude	g/MJ Gasoline
20	Congo	1.2	222	0.4%	14.8	620	4.65
19	Gabon	1.5	230	0.4%	17.9	748	5.62
18	Brazil	1.5	1833	1.0%	2.2	94	0.70
17	United Kingdom	1.6	1636	0.6%	2.7	112	0.84
16	Mexico	1.5	3477	8.3%	1.2	49	0.37
15	Azerbaijan	2.5	868	0.3%	7.9	330	2.48
14	Libya	2.5	1848	0.5%	3.7	155	1.16
13	Kazakhstan	2.7	1490	0%	5.0	208	1.56
12	Kuwait	2.7	2526	1.0%	2.9	123	0.92
11	USA	2.8	6978	40.7%	1.1	46	0.35
10	Equatorial Guinea	3.6	363	0.1%	27.2	1138	8.54
9	Indonesia	3.7	969	0.1%	10.5	438	3.29
8	Algeria	4.3	2000	2.6%	5.9	247	1.85
7	Qatar	4.5	1197	0%	10.3	431	3.24
6	Venezuela	5.4	2613	6.8%	5.7	237	1.78
5	Angola	6.8	1723	2.9%	10.8	453	3.40
4	Iraq	8.6	2145	2.9%	11.0	460	3.45
3	Iran	13.3	4401	0%	8.3	347	2.60
2	Russia (Total)	14.9	9978	0.7%	4.1	171	1.29
1	Nigeria	24.1	2356	6.4%	28.0	1173	8.81
	Total	5.485		75.7%			1.58

Attribution to oil production assuming 90% of flaring is associated with oil production.
U.S. venting emissions estimated at 43.36 g CH_4/mmBtu with average of 69.54 g CH_4/mmBtu as GREET default.
GREET oil processing leaks are inferred by subtracting combustion emissions from total methane from oil production with a default calculation of 15.33 g CH_4/mmBtu
Nigerian/U.S. on a gCO_2e/MJ basis = 25:1

GREET Defaults	
Flaring:	0.87
Venting:	1.65
Oil processing:	0.36

Life Cycle Associates (2009) Assessment of Direct and Indirect GHG Emissions Associated with Petroleum Fuels, Stefan Unnasch, Ralf Wiesenberg, & Susan Tarka Sanchez, for New Fuels Alliance, 94 pp., www.lifecycleassociates.com
Table 12. Estimate of Natural Gas Flaring in Oil Producing Countries, page 31.



Life Cycle Associates (2009), page 29.
Figure 5. Leading countries with flared gas emissions (Source: World Bank, EIA petroleum).

Cell: D234
Comment: Rick Heede:
World Bank / Global Gas Flaring Reduction Initiative (2005), GGFR Steering Committee Meeting: Presentations: Agenda #2: Demo Projects, London, 16Nov05, slide 30 of 55.
Note: GGFR underscores both "reported" flaring and "provisional". The group does not indicate suspected total flaring rates (above those reported).
The Top 20 Countries are responsible for 105 Bcm in 2004, of which Nigeria (24.1 Bcm), Russia (14.7 Bcm), and Iran (13.3 Bcm) are the top three.

Cell: D235
Comment: Rick Heede:
World Dry Gas Production from: Energy Information Administration International Energy Annual 2004, Table 2.4 World Dry Natural Gas Production, 1980-2004.

Cell: D236
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: D237
Comment: Rick Heede:
United Nations Development Programme / World Bank (2001) Africa Gas Initiative: Main Report, vol. 1, 55 pp. Estimates "4.8 Tcf of gas (135 Bcm) of gas is flared or vented worldwide."

Cell: D251
Comment: Rick Heede:
Conversion from BP Statistical Yearbook, glossary.

Cell: F254
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: B287
Comment: Rick Heede:
Heede, Richard (2003) ExxonMobil Corporation: Emissions Inventory 1882-2002: Spreadsheets, Climate Mitigation Services, "Vent&Flare" worksheet, at Cell F11. Cell comment in full:
Flaring of natural gas is common from production facilities without gas infrastructure or distant from consumer markets or with gas too poor in quality to market. As with venting practice, it is not possible to give an accurate picture of ExxonMobil's global flaring, much less do so over several decades of time, in dozens of production environments, without access to company records. It is clear, however, that flaring rates have declined dramatically over time -- especially, of course, near developed markets in the US -- and also that flaring rates remain high offshore and internationally.
We use three benchmarks:
Benchmark 1: The U.S. year 2000 average flaring rate: 4.5 million tonnes carbon divided by total US gas consumption of 336 million tonnes carbon = 1.34 percent. This is in a mature market with relatively stiff regulatory pressure to reduce waste and pollution, and we consider this flaring rate the minimum. Energy Information Administration (2001) Emissions of Greenhouse Gases in the United States, 2000, US DOE, Washington, p. 28.
Benchmark 2: ANL's GREET model cites 1996 "Worldwide NG Production and Flaring" at 4.6 percent (3,823 billion cf flared and annual production of 82,500 billion cf = 4.6 percent). Wang & Huang (1999) A Full Fuel-Cycle Analysis of Energy and Emissions Impacts of Transportation Fuels Produced from Natural Gas, Argonne National Laboratory, p. 36; www.transportation.anl.gov/
Benchmark 3: For a historical perspective on the flaring rate in the United States we use U.S. Bureau of Mines and EIA statistics. Flaring is not only ubiquitous, but the rate is far higher in distant locations, and in under-developed markets (which existed in the U.S. until natural gas market started to mature in the 1920s). Data for "Vented and Wasted" natural gas starting in 1920 indicate a high percentage declining gradually over time:
1920: 239 billion cf of 812 Bcf marketed = 29.4 percent;
1930: 519 Bcf of 1,979 Bcf marketed = 26.2 percent;
1940: 656 Bcf of 2,234 Bcf marketed = 24.00 percent;
1950: 801 Bcf of 6,282 Bcf marketed = 12.75 percent;
1960: 563 Bcf of 12,771 Bcf marketed = 4.41 percent;
1970: 489 Bcf of 21,921 Bcf marketed = 2.23 percent;
1980: 126 Bcf of 20,180 Bcf marketed = 0.62 percent;
1990: 150 Bcf of 18,594 Bcf marketed = 0.81 percent;
2000: 91 Bcf of 20,198 Bcf marketed = 0.45 percent.
Note: this is a fraction of natural gas flared; since most gas flared is actually unmarketable or wasted gas associated with oil production, we will tie the flaring fraction to aggregate oil sales for each company.
Source: Bureau of Mines (year unknown) Minerals Yearbook, Historical tables, M147-161, US Dept Interior (1920 and 1930)
Source: Energy Information Administration (2003) Natural Gas Annual, 2002, US DOE, Table 3 and historical data (1940-2000); www.eia.doe.gov/oil_gas/natural_gas/data_publications/natural_gas_annual/nga.html.
Benchmark 4: The Carbon Dioxide Information Analysis Center has estimated global CO2 emissions from gas flaring activities worldwide; this data set is shown on this worksheet (column R, with emissions from global gas consumption in column S, and the calculated flaring rate in column T). Note: we extend the flaring rate estimate back to 1900, since CDIAC starts flaring data in 1928; see comments in column T for details.
Source: Marland, G., T.A. Boden, & R.J. Andres (2002) Global, Regional, and National CO2 Emissions. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. http://cdiac.esd.ornl.gov/trends/emis/tre_glob.htm
Benchmark 5: Royal Dutch/Shell Group, which has published flaring statistics for the past several years, estimates that in 2001 it flared 10.3 million tonnes of carbon dioxide (2.81 million tonnes carbon MtC). Here we create three benchmarks based on Shell's flaring: 5a: per barrel of oil produced, 5b: per barrel of oil marketed, and 5c: per natural gas "made available for sale."
5a: 2.81 MtC over 810 million bbl produced ---> 2.81 MtC/85.3 MtC from the oil's combustion = 3.29 percent;
5b: 2.81 MtC over 2,242 million bbl marketed ---> 2.81 MtC/236.0 MtC from the oil's combustion = 1.19 percent;
5c: 2.81 MtC over 3,288 billion cubic feet of natural gas available for sale (47.2 MtC) ---> 2.81 MtC/47.2 MtC = 5.95 percent.
Source: calculated from Royal Dutch/Shell Group (2003) Financial and Operational Information, 1998-2002, p. 32, and the Shell climate site (www.shell.com).
Considerations: ExxonMobil's operations are increasingly overseas, where flaring rates are typically higher than in the U.S. (especially offshore, Africa, and the Middle East); flaring rates have declined sharply over the last several decades (especiallyin the U.S.); oil production facilities have been important sources of flaring; oil and oil products transport and storage continue to be sources or flared gas; finally, ExxonMobil's flaring rate is likely higher than industry leaders such as BP-Amoco and Shell Group (and therefore remains an important mitigation opportunity).
Conclusion: Inasmuch as flaring occurs throughout the production and supply chains of both natural gas and oil operations, we conclude that both hydrocarbon streams marketed by ExxonMobil should be bases of flaring emissions in the following manner:
Gas operations flaring emissions: 70 percent (0.7) of the global flaring rate estimated by CDIAC is applied to ExxonMobil's marketing of natural gas (carbon emissions from each company's gas sales time that year's CDIAC flaring rate in column V constitutes flaring emissions from XOM's gas operations (and that formula is: =('Natural Gas'!G33*V33)*0.7). Thus, we credit XOM with a smaller flaring rate than typical practice, in part due to XOM's operations being in more competitive markets, with more mature infrastructure, and a greater corporate emphasis on

marketing vs flaring natural gas.
Oil operations flaring emissions: 1.7 percent of carbon emissions from total oil sales (and that formula is: ='Aggreg Product'!G33*0.017).

Cell: B288
Comment: Rick Heede:
U.S. Government Accountability Office (2004) Natural Gas Flaring And Venting: Opportunities to Improve Data and Reduce Emissions, Report to the Honorable Jeff Bingaman, Cmte on Energy and Natural Resources, U.S. Senate, GAO-04-809, 36 pp. At page 12, "flaring and venting represent only 3 percent of the total natural gas production, ... qbout 100 billion cubic meters a year ..."

Cell: B289
Comment: Rick Heede:
World Bank / Global Gas Flaring Reduction Initiative (2005), GGFR Steering Committee Meeting: Presentations: Agenda #2: Demo Projects, London, 16Nov05, slide 30 of 55.
See calculations in table 27 above.
Note: GGFR underscores both "reported" flaring and "provisional". The group does not indicate suspected total flaring rates (above those reported).

Cell: B290
Comment: Rick Heede:
United Nations Development Programme / World Bank (2001) Africa Gas Initiative: Main Report, vol. 1, 55 pp. Estimates "4.8 Tcf of gas (135 Bcm) of gas is flared or vented worldwide."
See calculations in table 27 above.

Cell: B291
Comment: Rick Heede:
Marland, Gregg, T. A. Boden, & R. J. Andres (2002) "Global, Regional, and National CO2 Emissions." In Trends: A Compendium of Data on Global Change, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. DOE, http://cdiac.esd.ornl.gov/trends/emis/treglob.htm
Note: See CMS' "CDIACglobalcarbon1751-2002.xls" for details.

Cell: C291
Comment: Rick Heede:
CDIAC does not estimate flaring prior to 1950. It is worth noting that the flaring rates -- especially from associated gas (that is, associated with crude oil production, often in areas with no gas transportation infrastructure) -- were large since the early days of oil production, and indeed were probably a higher proportion prior to 1950. CMS has not documented the global quantities or flared gas proportions 1880 to 1950. See below for CMS quantification of US flaring and venting rates 1900 to 1950.

Cell: M307
Comment: Rick Heede:
Carbon dioxide is vented from both oil and gas production platforms and from gas processing facilities to reduce CO2 content and to meet pipeline gas specifications. Since facilities, rates, CO2 content, technology, and standard practice varies over time and space, an accurate inventory of emissions cannot be done for an oil and gas company without deep access to the operational data.
Benchmark 1: the US CO2 venting rate from natural gas operations (4.9 million metric tonnes carbon of CO2 removal from US natural gas production divided by total US gas consumption of 315 million tonnes carbon, or 1.53 percent, 1999 data).
Source: Energy Information Administration (2001) Emissions of Greenhouse Gases in the United States, 2000, US DOE, Washington, p. 28.
Benchmark 2: reducing CO2 content of sour gas from 3.0 mole percent CO2 to 2.0 mole percent CO2 results in the venting of 147.8 tonnes carbon per billion standard cubic feet processed. This alone is equivalent to a venting rate of 1.0 percent.
Source: American Petroleum Institute (2001) Compendium Of Greenhouse Gas Emissions Estimation Methodologies For The Oil And Gas Industry, p. 4-32.
Benchmark 3: The BuMines data shows "Vented and Wasted Gas" from 1936 to 1970 (ranging from a high of 26.5 percent of marketed gas production in 1944 to a low of 2.23 percent in 1970), but the table's footnotes do not elucidate what is being counted. We suspect the data is predominantly vented (that is, unflared) natural gas and flared natural gas, and probably does not include vented CO2.
Source: Bureau of Mines (year unknown) Minerals Yearbook, Historical tables, M147-161, US Dept Interior.
Benchmark 4: "Non-hydrocarbon gas removed from natural gas" (NHGR, which is predominantly carbon dioxide but also significant quantities of nitrogen, hydrogen sulfides, and helium; no data for each gas) is shown for 1980-2002. In 1980, the NHGR rate was 0.99 percent; in 1990 = 1.56 percent, and 2000 = 2.50 percent.
Source: Energy Information Administration (2003) Natural Gas Annual, 2002, US DOE, Washington, Table 3 plus historical data; www.eia.doe.gov/oil_gas/natural_gas/data_publications/natural_gas_annual/nga.html.
Conclusion: Consideration of all of these benchmarks leads us to increase the the EIA's venting rate from 1.53 percent by 1.15 percent to account for imports of natural gas (that factor divided domestic CO2 removal by total consumption; US imports was 18 percent in 2001). 1.53 x 1.15 = 1.76.
The formula is: =('Natural Gas'!columnGcell#)*0.0176

Cell: D328
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: L402
Comment: Rick Heede:
Revised from 2.1 Bcm in 2010 to 2.5 Bcm; 2.6 Bcm in 2011.

Cell: L404
Comment: Rick Heede:
World Bank revised USA 2010 flaring from 2.1 Bcm to 4.6 Bcm; up to 7.1 Bcm in 2011.

Cell: L413
Comment: Rick Heede:
Estimated Flared Volumes from Satellite Data, 2007-2011, http://go.worldbank.org/D03ET1BVD0 has been updated with 2011 data (140 Bcm), though deleting data for 2006.
Country revised data for 2010: Russia to 35.6 Bcm in 2010, Nigeria to 15.0 Bcm, Iran to 11.4 Bcm, Iraq to 9.4 Bcm, USA to 4.6 Bcm (including North Dakota), and total world from 134.0 Bcm in 2010 revised to 138.0 Bcm.

Cell: I469

Comment: Rick Heede:
The year 2005 data is from EPA's inventory report for 2008.

Cell: B472
Comment: Rick Heede:
EPA data covers numerous gas processing CO2 emissions (compressors dehydrator vents, Kimray pumps, and acid gas removal vents (AGR)), of which AGR gas removal accounts for 99.8 percent. EPA U.S. inventory, Appendix a, Table A-131.

Cell: B473
Comment: Rick Heede:
EPA 2008 inventory, Table A-132: CO2 Emission Estimates from the Natural Gas Transmission and Storage (Gg) total 0.061 MtCO2 for 2008; Table A-133: CO2 Emission Estimates from the Natural Gas Distribution Stage (Gg) totals 0.042 MtCO2. CMS attributes only CO2 emissions from gas processing plants.

Cell: I488
Comment: Rick Heede:
The year 2005 data is from EPA's inventory report for 2008.

Cell: B491
Comment: Rick Heede:
EPA data covers numerous gas processing CO2 emissions (compressors dehydrator vents, Kimray pumps, and acid gas removal vents (AGR)), of which AGR gas removal accounts for 99.8 percent. EPA U.S. inventory, Appendix a, Table A-131.

Cell: B510
Comment: Rick Heede:
nterstate Natural Association of America (2005) Greenhouse Gas Emission Estimation Guidelines for Natural Gas Transmission and Storage: Volume 1 - GHG Emission Estimation Methodologies and Procedures, revision 2,, by Innovative Environmental Solutions, Inc. for INGAA, 90 pp.

Cell: C516
Comment: Rick Heede:
EPA (2012) U.S. Inventory, Annex 3, Table A-134: CO2 Emission Estimates from the Natural Gas Production Stage (Gg) CO2) - converted to MtCO2.

Cell: F516
Comment: Rick Heede:
EPA (2012) U.S. Inventory, Annex 3, Table A-135: CO2 Emission Estimates from the Natural Gas Processing Plants (Gg CO2) - converted to MtCO2.

Cell: G516
Comment: Rick Heede:
EPA (2012) U.S. Inventory, Annex 3, Table A-136: CO2 Emission Estimates from the Natural Gas Transmission and Storage (Gg CO2) - converted to MtCO2.

Cell: H516
Comment: Rick Heede:
EPA (2012) U.S. Inventory, Annex 3, Table A-137: CO2 Emission Estimates from the Natural Gas Distribution Stage (Gg CO2) - converted to MtCO2.

Cell: J516
Comment: Rick Heede:
EPA (2012) U.S. Inventory, Annex 3, Table A-144: Summary of CO2 Emissions from Petroleum Systems (Gg CO2) - converted to MtCO2.

Cell: O516
Comment: Rick Heede:
CMS emission factor for crude oil & NGLs is detailed in and linked to the SUmOil.xls worksheet.

Cell: J519
Comment: Rick Heede:
CMS interpolates 1992 petroleum system emissions.

Cell: C557
Comment: Rick Heede:
EIA "International Energy Statistics" table on global Crude Oil including Lease Condensate, data on US 1990-2010.

Cell: F557
Comment: Rick Heede:
CMS emission factor for crude oil & NGLs is detailed in and linked to the SUmOil.xls worksheet.

Cell: C630
Comment: Rick Heede:
EPA (2012) pages 3-48 & 3-49: "The primary basis for estimates of CH4 and non-combustion-related CO2 emissions from the U.S. natural gas industry is a detailed study by the Gas Research Institute and EPA (EPA/GRI 1996). The EPA/GRI study developed over 80 CH4 emission factors to characterize emissions from the various components within the operating stages of the U.S. natural gas system. The same factors were used to estimate both CH4 and non-combustion CO2 emissions. CO2 factors were developed using the CH4 emission factors and average CO2 and CH4 content of gas. See Annex 3.4 for more detailed information on the methodology and data used to calculate CH4 and non-combustion CO2 emissions from natural gas systems."