LNG Supply-Chain Emissions Study: natural gas from Western Australia to Cabrillo Deepwater Port

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These estimates of supply chain emissions from fuel consumption, venting of CO2, flaring, and methane leakage are based on published BHP data to the extent possible. Reasonable and documented default values, emissions coefficents, and industry averages are also used in order to present as complete an inventory of the full range of emissions associated with BHP Billiton's Cabrillo Deepwater Port and the indicated quantities of natural gas sent out to SoCalGas company. This inventory encompasses emissions from the proposed source of the natural gas offshore Western Australia to ultimate combustion by SoCalGas' customers in California.

Annual Emissions

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Table 1	Scarborough Gas Production		
Total gas production	milllion cf per day	Bcf/yr	tonnes of gas (or LNG)
Offshore gas production platform	21	8	166,355
Pipeline to Pilbara LNG	13	5	103,945
LNG plant requirements	103	38	808,019
LNG carrier fleet requirements	88	32	691,770
Cabrillo Deepwater Port ops	13	5	102,447
Gas deliveries to SoCalGas	800	292	6,284,030
Total	1,038	379	8,156,565

Table 2	CO2 venting	Gas flaring	Methane	Methane	Platform energy	Prod'n Emissions
Gas production emissions	tonnes CO2/yr	tonnes CO2/yr	tonnes CH4/yr	tonnes CO2-eq/yr	tonnes CO2/yr	tonnes CO2-eq/yr
Total (low estimate)	31,042	31,042	11,054	254,242	337,533	653,859
Total (high estimate)	41,390	41,390	14,746	339,159	506,299	928,237
		CH4, % of gas prod'n	0.181%	Gas equiv. (average):	7.73	Bcf/yr

Table 3	Pipeline energy	Pipeline CH4	Pipeline CH4	Pipeline Emissions
Gas transportation	tonnes CO2/yr	tonnes CH4/yr	tonnes CO2-eq/yr	tonnes CO2-eq/yr
Pipeline to Pilbara LNG (low est.)	211,087	3,926	90,288	301,375
Pipeline to Pilbara LNG (high est.)	316,631	7,851	180,576	497,207
Gas equivalent (average of low & high):	4.83	Bcf/yr		

Table of conversions

1 tonne LNG	46,467	cubic feet gas
1 cubic meter LNG	21,189	cubic feet gas
1 cubic meter LNG	0.4560	tonne LNG
1 tonne LNG	2.1930	cubic meter LNG
1 tonne LNG	51.1138	million Btu
1 cubic meter LNG	23.3079	million Btu
1 million cubic feet gas	21.5206	tonnes LNG
1 million cubic feet gas	47.1943	cubic m LNG
1 nautical mile	1.1508	statute miles
1 horsepower (HP)	0.7457	kW
1 kW	1.3410	horsepower (HP)
1 million cf gas per day	7,885	tonnes LNG per yr
1 tonne	1.1023	short (US) tons
1 kg	2.2046	lb
1 cubic meter	35.3147	cubic feet
Combustion of 1 Bcf	54,602	tonnes CO2
1 tonne CO2	18,314	cubic feet gas
Combustion 1 m^3 LNG	1.1570	tonnes CO2
Combust'n 1 tonne LNG	2.5372	tonnes CO2

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Table 4	Darwin LNG (3.24 Mt/yr)			Pilbara LNG (7.07 Mt/yr) (low estimate)			Pilbara LNG (7.07 Mt/yr) (high estimate)		
Liquefaction plant	tonnes CO2/yr	tonnes CH4/yr	tonnes CO2-eq/yr	tonnes CO2/yr	tonnes CH4/yr	tonnes CO2-eq	tonnes CO2/yr	tonnes CH4/yr	tonnes CO2-eq
Refrigeration compressors	615,106		615,106	1,343,785		1,343,785	2,508,292		2,508,292
Power generation turbines (disc)	106,615		106,615	174,686		174,686	326,068		326,068
Acid gas venting (discounted)	574,350		574,350	209,125		209,125	209,125		209,125
Flaring	59,485		59,485	129,953		129,953	129,953		129,953
Venting (methane)		2,172	49,958		4,745	109,141		10,343	237,887
Other plant emissions (N2O)		2	474		3	1,035		5	1,448
Purchased electricity (not estimated)				(not estimated)			(not estimated)		
Total liquefaction plant (high & low)	1,355,556	2,174	1,405,988	1,857,549	4,749	1,967,724	3,173,438	10,348	3,412,773
			Gas equiv (low est.):	30.19	Bcf/yr	Gas equiv (high est):	54.29	Bcf/yr	

Estimated natural gas demand, LNG liquefaction (discounted average of low & high estimate 37.55 Bcf/yr

Emissions from BHP's proposed Pilbara LNG plant are estimated on the basis of ConocoPhillips' Darwin LNG facility. The Darwin plant adopted several emissions reduction initiatives, such as high-efficiency aero-derivative gas-fired turbines to power refrigeration compressors, waste heat recovery, ship vapor recovery, efficient pumps and motors, and cascading emissions benefits from smart design and technology. The Darwin plant likely emits far fewer greenhouse gases per unit of LNG produced than other LNG plants around the world, and may exceed the emissions performance of BHP's Pilbara plant designs.

BHP's proposed Pilbara LNG plant at Onslow, Western Australia, has been up-sized to meet BHP's estimated quantity of re-gasified LNG delivered to Cabrillo, namely 800 million cubic feet per day. Since the LNG carriers will consume LNG en route from Pilbara to Cabrillo, Pilbara must be scaled up from 6.0 to 7.08 Mt/yr in order to deliver the indicated LNG to Cabrillo. See the tables below for details.

Note: BHP's Pilbara gas feed is <1 percent CO2, compared to Darwin's more typical 6+ percent CO2. CMS has adjusted for Pilbara's low acid venting factor.

Table 5	Darwin	Pilbara
Scaling LNG plant	(Mt/yr)	(Mt/yr)
Delivery capacity	na	6.39
Gross production	3.24	7.08
Scale of Pilbara over Darwin:		2.185

Table 6	LNG production	GHG emissions	Emissions rate
Plant comparison	Mt/yr	MtCO2-eq/yr	tCO2-eq/tLNG
Darwin	3.24	1.41	0.43
Pilbara (low estim.)	7.08	1.97	0.28
Pilbara (high estim.)	7.08	3.41	0.48
Atlantic train 1	1.00	1.00	1.00
Atlantic train 2	2.23	2.03	0.91
Atlantic train 4	1.80	1.46	0.81
Total or average	22.43	11.27	0.50
		Atlantic #4/Darwin factor:	1.867

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Table 7	Onslow, Australia to Cabrillo		Vessel speed	Trip duration (one way)		Gas delivery rate at Cabrillo			
Shipping details	Miles	Nautical miles	Knots	Hours	Days	Million cf (gas)/day	m^3 LNG per day	m^3 LNG per year	tonnes LNG per year
(each LNG carrier, one way)	9,100	7,908	19.5	405.5	16.9	813	38,371	14,005,400	6,386,477

Table 8	Engine power		Emissions rate	Trip energy	Trip emissions		Equiv Gas	Equiv LNG	
Per LNG carrier emissions	brake HP	total kW	gCO2/kWh	kWh	kgCO2	tonnes CO2	million cf	tonnes	cubic meters
Low estimate (gas only mode)	60,000	44,742	430	18,144,180	7,801,997	7,802	143	3,075	6,743
Medium estimate (gas & diesel mode)	60,000	44,742	529	18,144,180	9,589,374	9,589	73	1,560	3,422
High estimate (diesel only mode)	60,000	44,742	630	18,144,180	11,430,833	11,431	na	zero	zero
Per LNG carrier emissions									
Methane, low estimate	grams CH4/HP-hr	0.35		kgCH4 per trip:	8,540		tonnes CO2-eq/trip	196	
Methane, high estimate	grams CH4/HP-hr	0.43		kgCH4 per trip:	10,438		tonnes CO2-eq/trip	240	

Table 9	Carrier capacity	LNG delivered	LNG carriers	Round trip emissions			Annual LNG Fleet operations		
LNG carrier fleet emissions	m^3 LNG	m^3 LNG	Landings per year	tonnes CO2	tonnes CH4	tonnes CO2-eq	tonnes CO2	CH4 in tonnes CO2-eq	tonnes CO2-eq
Low estimate (gas only mode)	138,000	124,513	112.48	15,604	17	393	1,755,160	44,189	1,799,349
Medium estimate (gas & diesel mode)	138,000	131,156	106.78	19,179	19	437	2,047,989	46,613	2,094,602
High estimate (diesel only mode)	138,000	138,000	101.49	22,862	21	480	2,320,194	48,731	2,368,925
						Gas equivalent (gas-mode):	32.14	Bcf/yr	

Table 10	Equipment	Carbon dioxide	Methane	Methane	Total Cabrillo Ops	Cabrillo Start-Up
Cabrillo Deepwater Port	rating (each)	tons CO2/yr	tons CH4/yr	tons CO2-eq/yr	tonnes CO2-eq/yr	tonnes CO2-eq
4 Wartsila 9L50DF generators	8,250 kW	54,752	20.9		50,107	9,267
4 submerged cmbust'n vaporizers	115 million Btu/hr	215,271	3.5		195,365	na
2 tug boats	15,000 BHP	12,006	12.9		11,161	?
1 crew boat	1,500 BHP mains	332	0.4		309	?
LNG carrier (LNG offloading)	60,000 BHP total	4,492	4.8		4,175	na
Miscellaneous sources		372	0.4		346	356
Cabrillo operations, low estimate		287,225	43	986	261,463	9,623
Additions: construction: methane			35	805	730	730
Additions: methane FSRU operations			8,075	185,726	168,489	
Additions to BHP: vessels & equip. (CO2)	1.06 million glns diesel					10,800
Additions: electricity & misc (not est.)					na	na
Additions: project materials (not est.)	700,000	tonnes CO2 from steelmaking: not included			na	na
Cabrillo operations, high estimate					430,682	21,153
	Gas equivalent:	4.76	Bcf/yr			
	Equivalent LNG	102,699	tonnes/yr			

Table 11	US methane 2004	Methane rate
Methane rate	million tonnes CH4	tonnes CH4/Bcf
US consumption (Bcf)	22,321	
Gas production	1.86	83.33
Gas processing	0.63	28.22
Transmission, storage	2.36	105.73
Gas distribution	1.79	80.19
Incomplete combust'n	0.02	0.93
Total gas industry	6.66	298.40

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Table 12	Gas delivered to SoCalGas		Methane leakage: gas distribution & combustion			Non-fuel uses		Non-combusted	Total combusted	Total emissions
Gas delivery & combustion	Million cf (gas)/day	Billion cf per year	Rate: tonnes CH4/Bcf	tonnes CH4	tonnes CO2-eq	tonnes CO2 sequestered		tonnes CO2 sequestered	tonnes CO2/yr	tonnes CO2-eq/yr
Low estimate	800	292	86	25,124	577,862	48,629		79,719	15,815,494	16,393,356
High estimate	800	292	108	31,406	722,327	24,314		31,888	15,887,640	16,609,968
			CH4 leakage of total del	0.39%						

Table 13	LNG Supply-Chain Emissions Summary - Low Estimate							Average of Low & High Estimates			
	Carbon Dioxide	Methane	Methane	Total GHG	Total GHG			Carbon Dioxide	Total GHG	Total GHG	
Emissions Sum (Low est.)	tonnes CO2/yr	tonnes CH4/yr	tonnes CO2-eq/yr	tonnes CO2-eq/yr	US tons CO2-eq/yr	Percent of low:		tonnes CO2/yr	tonnes CO2-eq/yr	US tons CO2-eq/yr	% ave
Gas production (Scarborough)	399,617	11,054	254,242	653,859	720,749	3.1%	Pn	494,348	791,048	871,973	3.5%
Gas transportation	211,087	3,926	90,288	301,375	332,206	1.4%	Pl	263,859	399,291	440,138	1.7%
Liquefaction plant	1,857,549	4,749	110,176	1,967,724	2,169,023	9.2%	Liq	2,515,493	2,690,249	2,965,461	11.8%
LNG carrier fleet	1,755,160	1,921	44,189	1,799,349	1,983,422	8.4%	LNG	2,047,989	2,094,602	2,308,879	9.2%
Cabrillo Deepwater Port Ops	260,569	39	894	261,463	288,210	1.2%	Cb	260,569	346,072	381,475	1.5%
Cabrillo Start-Up (annualized, 25yrs)	373	1	12	385	424	0.0%	Su	410	438	483	0.0%
Customers of BHP-delivered gas	15,815,494	25,124	577,862	16,393,356	18,070,397	76.7%	En	15,851,567	16,501,662	18,189,782	72.3%
Total Supply Chain emissions	20,299,849	46,813	1,077,663	21,377,512	23,564,431	100%	Tt	21,434,235	22,823,362	25,158,192	100%

Percent of total relative to combustion of the natural gas: 135.2%

Total relative to combustion: 144.0%

CH4/total (low): 5.0%

CH4/total (average): 6.1%

Table 14	LNG Supply-Chain Emissions Summary - High Estimate							Average of Low & High Estimates		
	Carbon Dioxide	Methane	Methane	Total GHG	Total GHG			Methane	Methane	Methane
Emissions Sum (High est.)	tonnes CO2/yr	tonnes CH4/yr	tonnes CO2-eq/yr	tonnes CO2-eq/yr	US tons CO2-eq/yr	Percent of high		tonnes CO2-eq/yr	US tons CO2-eq/yr	Percent of total CH4
Gas production (Scarborough)	589,079	14,746	339,159	928,237	1,023,196	3.8%	Pn	296,700	327,053	21.37%
Gas transportation	316,631	7,851	180,576	497,207	548,071	2.1%	Pl	135,432	149,286	9.75%
Liquefaction plant	3,173,438	10,348	239,335	3,412,773	3,761,900	14.1%	Liq	174,755	192,633	12.58%
LNG carrier fleet	2,320,194	2,119	48,731	2,368,925	2,611,266	9.8%	LNG	46,613	51,381	3.36%
Cabrillo Deepwater Port Ops	260,569	7,357	169,219	430,682	474,741	1.8%	Cb	85,057	93,758	6.13%
Cabrillo Start-Up (annualized, 25yrs)	447	2	44	491	541	0.0%	Su	28	31	0.00%
Customers of BHP-delivered gas	15,887,640	31,406	722,327	16,609,968	18,309,168	68.5%	En	650,095	716,599	46.81%
Total Supply Chain emissions	22,547,997	73,829	1,699,392	24,248,283	26,728,883	100%	Tt	1,388,680	1,530,741	100.00%

Percent of total relative to combustion of the natural gas: 152.6%

CH4/total (high): 7.0%

Carbon Dioxide	Carbon Dioxide	Carbon Dioxide
tonnes CO2/yr	US tons CO2/yr	Percent of total CO2
494,348	544,920	2.31%
263,859	290,852	1.23%
2,515,493	2,772,828	11.74%
2,047,989	2,257,498	9.55%
260,569	287,225	1.22%
410	452	0.00%
15,851,567	17,473,183	73.95%
21,434,235	23,626,958	100.00%

Table 15	Comparing total supply-chain emissions to US and California emissions					
	Total US GHG	LNG supply chain (this study)		Total Calif. CO2	LNG supply chain (this study)	
Emissions Sum	tonnes CO2-eq/yr	tonnes CO2-eq/yr	tonnes CO2-eq/yr	tonnes CO2/yr	tonnes CO2 only	tonnes CO2 only
	2004	low estimate	high estimate	CO2 only	low estimate	high estimate
		21,377,512	24,248,283	2001	20,299,849	22,547,997
		percent of US	percent of US		percent of California	percent of California
	7,122,100,000	0.300%	0.340%	383,100,000	5.30%	5.89%

Cell: B23
Comment: Rick Heede:
Table 1 estimates the total quantity of natural gas production necessary to supply (a) the 800 million cubic feet BHP has indicated it will provide to SoCalGas, (b) the additional natural gas required for gas production platforms, pipeline fuel, for combustion equipment at the Pilbara liquefaction plant, as LNG carrier propulsion fuel, and gas consumed by the Cabrillo FSRU for regasification and other uses.

Cell: E23
Comment: Rick Heede:
Total gas production is not based on the productive capacity of BHP Billiton's & ExxonMobił's jointly owned Scarborough natural gas field. The purpose is to estimate the total amount of natural gas required for the entire supply chain IF the objective is to deliver 800 million cubic feet of natural gas to SoCalGas via the proposed LNG plant at Pilbara using gas from Scarborough and shipped to Cabrillo for regasification and delivery in California. CMS has estimated both high and low natural gas demand for major elements of this supply chain, which, of course, requires additional natural gas to be produced at Scarborough and sent down the supply chain. We have averaged the high and low demand estimates in this total Bcf production column in order to enable downstream estimates to use one datum for aggregate natural gas required. This analysis is based on Scarborough and Pilbara since BHP has indicated these facilities as likely sources of gas and LNG, respectively.

This is an approximation of the quantity of Scarborough natural gas production required per annum (and per day), based on a delivery of 800 million cubic of gas regasified at Cabrillo per day, and accounting for the the amounts of natural gas (or their equivalent in natural gas liquids or purchased energy) used at the Scarborough offshore production platform, to run pipeline compressors for the 280-km subsea pipeline to the onshore Pilbara LNG plant near Onslow, Western Australia. Also included are the natural gas requirements to fuel the LNG carrier fleet, which uses boil-off gas and vaporized LNG during the trans-Pacific crossing, and, finally, natural gas used to power generators and produce heat for the vaporizers at the Cabrillo Deepwater Port. The amount of natural gas that BHP indicates will be delivered to SoCalGas (and comprises the design basis for the Cabrillo FSRU engineering) totals 292 billion cubic feet (Bcf) per annum. The parasitic loads mentioned above add 84 Bcf/yr, or nearly 29 percent to the quantity proposed to be delivered.

BHP may elect to acquire natural gas from another field in Australia, or to contract for LNG delivery from Indonesia or another LNG plant. For that matter, we cannot ascertain whether BHP's plans for Scarborough and/or Pilbara LNG will be sufficient to meet the estimated total demand. This uncertainty is immaterial, really. What is important is to estimate the total natural gas requirement and the associated emissions of greenhouse gases. Of course, gas fields differ in terms of carbon dioxide content of the feed gas delivered to LNG plants, and the efficiency and emissions of LNG plants also vary significantly. Indeed, the emissions rates as modeled for this analysis are significantly below world averages for two principal reasons:

(1) Scarborough natural gas contains ~one percent carbon dioxide (meaning that less CO2 has to be removed prior to liquefaction; removed CO2 is typically vented to the atmosphere).

(2) the emissions rate -- measured as tonnes of CO2-equivalent per tonne of LNG produced -- of ConocoPhillips' Darwin LNG plant on which we base the proposed Pilbara plant's performance is significantly below world average.

Cell: E24
Comment: Rick Heede:
The gross amount of natural gas produced at Scarborough includes a quantity of gas consumed at the production platform and for pipeline propulsion as shown in Tables 2 and 3. While this gas usage emits carbon dioxide, it does not require additional liquefaction capacity at Pilbara. This column shows total gas consumption in tonnes.

Cell: L31
Comment: Rick Heede:
Conversion sources:
U.S. Dept of Energy (2005) Liquefied Natural Gas: Understanding the Basic Facts, p. 9;
miscellaneous engineering sources;
and calculations by CMS.

Cell: B37
Comment: Rick Heede:
Table 2 estimates emissions from venting, flaring, and natural gas consumption at production platforms such the Scarborough gas field. Since Scarborough is shut in, and no production platform has been deployed, we industry standards to estimate emissions. Our estimates are based on total gas production required to deliver the quantity cited by BHP in its Permit Application, anmely 800 million cf per day; this estimate is derived in Table 1.

Cell: C37

Comment: Rick Heede:
We assume a CO_2 gas venting rate of 0.15 percent (low estimate) to 0.25 percent (high estimate) at the Scarborough gas production platform. Formula = Total gas production *0.0025 * tonnes CO_2/Bcf combusted.

Note: a similar calculation for CO_2 venting emissions from sour gas processing is made in API (2001) Compendium of Greenhouse Gas Estimation Methodologies, p. 4-32.

Cell: D37
Comment: Rick Heede:
We assume a gas flaring rate of 0.15 percent (low estimate) to 0.20 percent (high estimate) of throughput. While probably conservative, gas flaring data in natural gas production is scarce. EIA data show a total flaring rate of 0.451 percent (91 Bcf flared of 20,198 Bcf marketed), but this is an industry total, not merely gas production. Note: gas flaring rates have declined sharply as markets and technology have improved: 29 percent in 1920, 12.8 percent in 1950, 0.81 percent in 1980, etc. Source: Heede (2003), spreadsheet on Venting and Flaring, cell note F11. Note also that global flaring rates remain quite high: Oak Ridge CDIAC data show total emissions from flaring equal to 2.0 percent of emissions from gas combustion (28 MtC of 1,348 MtC in 2002); this, however, is flaring from both gas and oil operations.

Note: A much wider range of gas production platfform flaring is suggested by : “Of ten Norwegian platforms the percentage of the gas production flared varied from 0.04 to 15.9. The volume of gas flared is usually higher on an oil production platform than on a gas production platform, since it is preferred to sell the gas rather than to flare it if there is a choice. Generally, the volume flared is higher on new platforms than on the old because the elder have had time to develop better procedures, have fewer shut downs and practice more direct venting of the gas.”Source: European Environment Agency (2005) Emission Inventory Guidebook: Section B926: Flaring in Gas & Oil Extraction, EMEP/CORINAIR, http://reports.eea.eu.int/EMEPCORINAIR4/en.

Cell: E37
Comment: Rick Heede:
Routine and fugitive emissions of methane is common at production platforms, and average 83.33 tonnes of CH_4 per Bcf of gas produced, according to US EIA data. Since methane is a greenhouse gas 23 times more potent than carbon dioxide (100-year time horizon), even modest quantities will result in large relative emissions. We conservatively apply one-half (low estimate) to two-thirds (high estimate) of the average US methane emissions rate for natural gas production facilities -- that is, 83.33 tonnes of methane per 1 Bcf of gas production * 0.50 and 0.667, respectively.

EPA (2006) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004, Appendix G: Methodology for Estimating CH_4 Emissions from Natural Gas Systems, shows 1,467 Gg (1.467 million tonnes) of methane from natural gas production for 19.4 Tcf produced in 2001, or a rate of 75.62 tonnes of CH per Bcf produced. Table G-1 shows activity data,# but it cannot be aggregated in any meaningful sense to show typical emissions per offshore production platform.

#: blowdowns, pressure relief valves, mishaps, compressors, peneumatic device vents, etc.

Source: European Environment Agency (2005) Emission Inventory Guidebook: Section B521: Table 8.24 (p. 19) suggests that large gas production platforms incorporate 8,300 gas connectors, 3,000 valves, 65 pressure relief devices, and 560 other components.

Another source: API (2001), p. 4-67: Table 4-21. Facility-Level Average Fugitive Emission Factors shows 16.25 lb CH_4 per million Scf of natural gas production at offshore platforms. This means, for Scarborough’s production level, 16.25 lb CH_4/million Scf * 1,031 million Scf/day * 365 day/yr = 3,057.6 tons of CH_4 per year (2,773.8 tonnes/yr). This is substantially lower than the EIA approach applied above. API’s facility-level methane emissions rate is 40.63 lb CH_4 per million Scf produced onshore.

BHP will be in a position to correct or refine -- as well as publish -- the Scarborough fugitive emissions estimate made here once the platform designs are complete.

In view of the lower API emission factors for offshore gas production platforms CMS has adjusted the EIA factors by multiplying both the low and high estimates described above by 0. 7; that is, reduce each factor by 30 percent.

Cell: G37
Comment: Rick Heede:
We conservatively assume that 0.5 *3.262 percent (low estimate) to 0.75 * 3.262 percent (high estimate) of gross gas production is used to fuel generators, hotel loads, heating requirements, and other platform energy demand such as lighting and pumps and compressors.

Data for the U.S natural gas industry shows 3.262 percent for 2004 (Natural Gas Consumption by End Use, 1997-2005, EIA): Lease gas consumption = 731.56 Bcf, of Total gas consumption of 22,430.23 Bcf = 3.262 percent.

Cell: B47
Comment: Rick Heede:
This table estimates energy use and emissions from the subsea pipeline linking the Scarborough natural gas field to the onshore Pilbara LNG facility at Onslow, Western Australia.

Cell: C47
Comment: Rick Heede:
Compressors to pressurize gas pipelines use large quantities of energy. A typical gas pipeline moves gas at approximately 50 km per hour, and deploy compressors every 80 to 96 km along its length with power ratings of about 4,000 to 10,000 HP.

BHP has not published pipeline engineering specifics for the proposed BHP/ExxonMobil pipeline from Scarborough to onshore facilities at Pilbara. CMS instead uses EIA gas industry data and assumes 0.4 * 2.5495 percent (low estimate) to 0.6 * 2.5495 percent (high estimate) of the throughput energy for BHP's 270-km proposed subsea link between the Scarborough gas field and the LNG plant at Onslow, Western Australia. That is, forty to sixty percent of the total amount of natural gas consumed by pipeline compressors and related uses in the US (see below). Some of the remainder will be applied to SoCalGas gas distribution, whereas this fraction is applied to gas transportation between Scarborough and Pilbara LNG plant.

Data for the U.S natural gas industry shows 2.55 percent for 2004 (Natural Gas Consumption by End Use, 1997-2005, EIA): Pipeline and distribution use = 571.85 Bcf, of Total gas consumption of 22,430.23 Bcf = 2.5495 percent. This is supported by an analysis by Rose (1979): "Gas pipelines are also more energy-intensive, using about 2.5 percent of the energy transported or five to six times as much as for oil or oil-product pipelines."Rose cites statistics from J. N. Hooker of ORNL of gas pipelines using 2,000 Btu per ton-mile, compared to oil pipelines using 320-360 Btu/ton-mile (stats from late 1960s-early 1970s).

Cell: D47
Comment: Rick Heede:
Methane emissions (routine leakage through seals, valves, joints, and related infrastructure) for gas transmission and storage average 105.7 tonnes of CH_4 per Bcf of gas consumed in the United States (2004, EIA data). Since the Scarborough to Pilbara LNG plant is a subsea pipeline, and "only" 280-km in length, we apply a leakage rate of ten percent (low estimate) to twenty percent (high estimate) of this US average.

API (2001) Compendium, Table 4-21 Facility-level Average Fugitive Emissoin Factors, p. 4-67, show 1,259,400 lb CH_4 per gas transmission compressor station-year, or 630 tons (571 tonnes) of methane per compressor-year. We do not know how many equivalent compressors will be required for the 280-km subsea pipeline from Scarborough to Pilbara. The American Gas Association notes that there is typically (on land, at least) one compressor station every 50 to 60 miles (80.5 to 96.6 km). The Scarborough to Pilbara pipeline would thus require the equivalent of 2.9 to 3.5 such compressors. Further research may suggest a more appropriate methane emissions factor for the Scharborough pipeline to onshore facilities; such research, however, is beyond the scope of this simple analysis made without access to BHP design criteria.

Cell: B51
Comment: Rick Heede:
We estimate the gas consumption in Bcf of pipeline energy used to transport gas by subsea pipeline from the offshore Scarborough gas field to Pilbara LNG plant. See "pipeline energy" for details.

Cell: E67
Comment: Rick Heede:
ConocoPhillips published (per Australian law) an Environmental Management Plan for its 10 million tonne per year LNG facility near Darwin, Australia. While the facility may be expanded to 10 Mt/yr, Table 5.3 shows "Darwin LNG Plant Projected Normal Operations Air Emissions for 3.24 Mt/yr Nominal Annual Average Production Rate," p. 5-10. This is data for Darwin's first LNG train. These emissions estimates are summarized for the Darwin plant below and used as the baseline for BHP's emissions for its LNG facility at Pilbara near Onslow, Western Australia. Darwin's baseline emissions rates are scaled up to Pilbara's larger plant size in Table 5.

ConocoPhillips Petroleum Company (2005) Darwin LNG: Operations Environmental Management Plan, DLNG/HSE/PLN/001, rev.1, www.darwinlng.com/Environment/Index.htm

Darwin LNG report Table 5.2 shows "Estimated Annual Hydrocarbon Flaring and Venting Volumes for the 3.24 Mtpa Normal Operations Case," (p. 5-7). It details routine and expected non-routine flaring volumes, plus venting of methane in the plant's nitrogen rejection units (NRU) and acid gas venting. The NRU data shows methane component only (at 2.887 million Nm^3 per year), whereas the acid gas venting is chiefly CO_2 (99.85 percent of 7.235 million Nm^3/yr) and a small (0.13 percent) of methane.

Cell: H67

Comment: Rick Heede:
BHP is in the pre-feasibility phase of evaluating its proposed Pilbara LNG plant. The preferred site is a few km outside Onslow, Western Australia. The proposal includes the construciton of a 280-km subsea pipeline from BHP/ExxonMobil's Scarborough natural gas field to the Pilbara onshore site. Scarborough is shut in, and has been evaluated to contain 8 trillion cubic feet (Tcf) of recoverable natural gas.

While the pre-feasibility study shows the Pilbara plant at 6.0 million tonnes of LNG per year, its capacity will, in actuality, have to be somewhat larger if it is to produce sufficient quantities of LNG as required by the company's estimated natural gas delivery rate of 800 million cubic feet per day to SoCalGas via Cabrillo. And Pilbara's gross capacity must be larger still to account for the LNG consumed by its fleet of LNG carriers en route to and return from Cabrillo. This scaling calculation is shown in Table 5.

Note: this calculation also accounts for LNG (whether boil-off or re-gasified) required for FSRU operations, shown in Table 10 "Cabrillo Deepwater Port."

Note: Since the power demand associated with acid gas removal is also reduced due to lower CO2 content in Pilbara's feedgas, we assume that emissions from power generation turbines are decreased by 0.25 of the scale-up factor shown in Table 5 (that is, scaled up by 75 percent rather than 100 percent).

Cell: L67
Comment: Rick Heede:
The low estimate for BHP's proposed (but uncharacterized) liquefaction plant is simply the emissions rate (in tonnes of CO2 per tonne of LNG) of the Darwin high-efficiency / low-emission faciltiy amply characterized in ConocoPhillip's reports, albeit pre-operational estimates of emissions.

In this high emissions estimate of the Pilbara LNG plant we assume the same low acid gas venting rate (since feed gas from Scarborough is only ~1.0 percent CO2), but average the emissions rates from Darwin and the Atlantic Train 4 (the newest plant installed at this Trinidad facility, which emissions are estimated in Diocee et al, 2004). Assuming Atalntic Train #4's emissions coefficient increases Pilbara's emissions from energy use in compressors from 0.434 tCO2/tLNG to 0.81 tCO2/tLNG, or by a factor of 86.64 percent. While this a broad range, it conforms to the spread of emissions factors for recently-built LNG facilities, and both Darwin and Atlantic use high-efficiency equipment. Also, so as to make the comparison valid, the Atlantic Train #4 emissions also exclude acid gas venting.

In sum, the formula for compressor and generation emissions are (Pilbara low estimate) * 1.867.

Cell: B69
Comment: Rick Heede:
ConocoPhillips has installed six aero-derivative LM2500 gas-fired turbines. The company estimates total six-pack emissions of 615,106 tonnes of CO2 per year.

Cell: B70
Comment: Rick Heede:
ConocoPhillips uses three Solar Taurus 60s and two Solar Taurus 60 dual-fuel turbines for power generation. The company estimates emissions for both ship-loading and other power demands totaling 106,615 tonnes of CO2 per year.

Pilbara's emissions from power generation turbines are discounted (by 25 percent from the scale-up formula) in order to account for decreased energy requirements for acid gas venting of Pilbara's low carbon dioxide content Scarborough feed gas.

Cell: B71
Comment: Rick Heede:
Natural gas processing facilities -- including LNG plants -- vent CO2 contained in the feed gas. (While carbon sequestration programs are being engineered and installed at several oil and gas production sites, we are not aware of any efforts to re-injector otherwise sequester CO2 emissions from gas processing plants.)

In Darwin's case, the gas comes from the Bayu-Undan field 500 km west of Darwin via a 26-inch subsea gas line. This gas contains about 6 percent CO2, which is considerably higher than the feed gas from BHP's Scarborough field (reportedly 1.0 percent or less). This feed gas difference argues for reducing the scaling factor applied to compressor and flaring emissions with respect to BHP's proposed Pilbara development by about 6+ relative to ~1 percent, say by 1:6, or from 2.17 to 2.17/6 = 0.361.

Yates (2004) puts Darwin's feed gas at "over 6% carbon dioxide," p. 8.

Cell: B72

Comment: Rick Heede:
The Darwin Environmental Management Plan also details emissions estimates for the numerous flares common at gas processing facilities, such as flash gas, marine flares, condensate flares, and so on. These total 59,485 tonnes of CO_2 per year.

Cell: B73
Comment: Rick Heede:
ConocoPhillips's (2005) Darwin EMS, note to Table 5.2, states: "A routine venting operation. Only the methane vented volumes are presented, because other gases are neither greenhouse gases nor air pollutants. The methane emission rate is 268.8 kg/h with duration of venting assumed to be 7,671 hours per year." 268.8 kg/h times 7,671 hr/yr = 2,062 tonnes of methane. On its Table 5.3, annual "TOC/CH_4 venting totals 2,172.1 tonnes.

CMS has updated the GWP factor from 21 to 23xCO_2, per IPCC's TAR report (2001), p. 388.

Cell: K73
Comment: Rick Heede:
Using the scaling factor applied to compressors (based on the Atlantic Train #4 relative to the Darwin emissions rate) results in a methane emissions estimate of 6,604 tonnes of CH_4. CMS instead applies the methane emissions rate of the US natural gas processing industry (Table 11), namely 28.22 tonnes of CH_4 per Bcf of natural gas consumption, which, in the case of the scaled-up Pilbara plant, totals 366 Bcf per year (see Table 1).

Cell: B74
Comment: Rick Heede:
ConocoPhillips included emissions of nitrous oxide, chiefly from stationary combustion sources. 1.6 tonnes of N_2O is cited; CMS has updated their GWP factor to 296xCO_2, per IPCC's TAR report (2001), p. 388.

Cell: B75
Comment: Rick Heede:
An entity may elect to sets its emissions boundaryto include emissions from power plants providing electricity to the site. Since the Darwin LNG plant EIS is following Australian reporting guidelines (which, of course, focus on new facility emissions), no such emissions are included. CMS cannot estimate the quantity of power purchased by either Darwin or the proposed Pilbara plant, and all required power is assumed to be generated onsite. If Pilbara will require grid-connected power purchases, future supply-chain emissions estimates should quantify associated CO_2 emissions.

Cell: E77
Comment: Rick Heede:
LNG compressors and power generators at LNG plants are sometimes fueled with natural gas liquids. To our knowledge, BHP has not published the composition of Scarborough gas, and we assume that the proposed Pilbara LNG plant will use natural gas to run the energy-intensive liquefaction and related systems. In practice, an LNG plant may also use entrained natural gas liquids to fuel some plant equipment. CMS calculates the equivalent quantity of natural gas required to run BHP's proposed Pilbara plant. This calculation estimates the amount of natural gas combusted in power generation equipment equal to the emissions estimates for those same functions at ConocoPhillips' Darwin plant -- even though BHP may build an LNG facility with less efficient combustion and process systems. The gas consumption estimate also adds flaring emissions and gas used in power generation turbines (which itself discounted for lower CO_2 content in the gas feed than at Darwin). The estimate excludes emissions from acid gas venting.

Cell: J79
Comment: Rick Heede:
This averages the high and low estimates of gas consumption for liquefaction, including compressors, power generation turbines (discounted, as explained above, for lower power demand based on low CO_2 content of the Scarborough feed gas), and flaring. It excludes emissions from acid gas venting (other than the power required to do so). While Pilbara may well use natural gas liquids for part of its energy supply, rather than relying exclusively on "parasitic" use of its natural gas, we do not have any data showing NGL content of Scarborough gas. However, we discount this average to account for some NGL usage: formula: (low + high)/2.25

Cell: B95
Comment: Rick Heede:
The detailed estimate made of ConocoPhillips' Darwin LNG plant emissions must be scaled to each plant's LNG production capacity. The Darwin emissions are based on a facility producing 3.24 million tonnes of LNG per year (Mt/yr, or Mtpa) by the completion of its first liquefaction train in early 2006. Emissions vary plant by plant based on a numberof variables, the most important being technology selection (gas turbines, steam, or electric compressors), feed gas, facility age, and environmental regulations.

Since BHP's Pilbara pre-feasibility study has not been published a site-specific emissions estimate cannot be made in lieu of BHP's own forthcomng estimates. We can, however, scale up the estimated Darwin emissions based on a LNG train capacity of 3.24 Mt/yr to Pilbara's anticipated capacity. We assume that the Darwin facility is subject to the same Federal regulations facing BHP in Onslow, Western Australia, and that both facilities will employ modern technology and be required to mitigate process and energy-related emissions. Pilbara's feed gas is expected to come from Scarborough natural gas field 280 km northwest of Onslow, and that gas has a carbon dioxide content of less than 1.0 percent, per BHP data.

BHP has stated that Pilbara LNG plant will be a 6 million tonne per year facility. This, however, is not sufficient to deliver the promised amount of LNG to Cabrillo (being short by ~1.07 Mt/yr), given that 800 million cf per day of natural gas is projected to be re-gasified at Cabrillo and delivered to SoCalGas (total gas production is derived in Table 1).

As shown in the "LNG carrier fleet emissions" table below, such a delivery projection translates to 13.99 m^3 of LNG per year once the FSRU's own gas requirements of approximately 12 million cf/day are added, and once the fuel requirement of each LNG trans-Pacific round-trip is accounted for (6,743 m^3 one-way), each LNG carrier will depart with 138,000 m^3 and deliver 124,513 m^3 of LNG. This ratio drives the estimated scale-up of the Pilbara plant from 6.38 Mt/yr to 7.07 Mt/yr. (These numbers are subject to change.)

Rather than increase the planned size of Pilbara, BHP may instead elect to contract for LNG from another plant -- in Indonesia, for example -- or buy LNG on the emerging spot market. But our intention here is to estimate total emissions from a LNG supply chain that delivers 800 million cf/day to Cabrillo (plus Cabrillo's gas usage), regardless of the eventual source of the LNG.

In sum, we estimate Pilbara emissions of carbon dioxide and methane on the basis of scaling Darwin's emissions by a factor of 2.18 to reflect Pilbara's 118 percent larger capacity requirement.

Cell: I95
Comment: Rick Heede:
To the best of our knowledge, this table compares the emissions performance of several LNG plants and/or trains using the same measurement criteria and sources. That is, acid gas venting is not included, although the emissions from generating electricity (including power requirements of CO2 removal). Nonetheless, uncertainties remain, and these comparisons could be greatly improved by access to company data. Also, data from other LNG plants and liquefaction trains would be extremely useful, particularly those using different technology.

Cell: D116
Comment: Rick Heede:
Approximate; estimated on the basis of air travel distance between Los Angeles and Perth (9,310 miles), minus 210 miles. Or LAX to Darwin (7,870 miles) plus ~1,240 miles for Onslow to Darwin.

1 nautical mile = 1.151 statute miles.

Cell: E116
Comment: Rick Heede:
Assumed vessel speed is based on published data on new LNG shipbuilding orders. Maritime Business Strategies's (Tim Colton) "LNG Carrier Construction Activity in 2006" lists Basin of operation, owner, yards, sizes (the average size of 23 new orders is 209,000 dwt). The Pacific Eurus (owned by LNG Marine Transport and serving Tokyo Electric's run between Darwin Australia [ConocoPhillips' Darwin LNG] and Japan) is 137,000 m^3, cost $180 million, has four Moss tanks, flies a Bahama flag, and cruises at 19.0 knots.

Source: www.coltoncompany.com/shipbldg/worldsbldg/gas/lngactivity2006.htm

Cell: G116
Comment: Rick Heede:
Simple division of estimated nautical miles of route (one way) by average vessel speed.

Cell: H117
Comment: Rick Heede:
"The Project will have a capability of regasifying up to a maximum capacity of 1.5 Bcf/day, with a normal rate of between 0.6 Bcf/day and 0.9 Bcf/day, or about 800 million cubic feet per day." BHP, p. 1-3.

BHP emissions estimates are indeed based on FSRU throughput of 800 million cf per day, 365 days per year, total 292 billion cf per year. BHP Permit, Appendix A, Table FSRU 9, Submerged combustion vaporizer emissions summary.

We thus add 800 million cf per day to estimated gas requirements for FSRU regasification and other "parasitic" gas loads (gas to run generators, hotel loads, and other loads identified by BHP. These total 12.2

million cf per day and are estimated at the bottom of Table 10 by converting BHP's estimated FSRU emissions of 287,225 tons of CO2 into equivalent natural gas (4.46 Bcf).

Cell: D123
Comment: Rick Heede:
We assume propulsion by Wartsila 18V50DF dual-fueled engines with emissions of diesel mode: 630 gCO2/kWh (100% load); gas mode: 430 gCO2/kWh (100% load). The Wartsila 18V50DF generates 17,100 kW (950 kW per cylinder).

Cell: F123
Comment: Rick Heede:
Trip energy is calculated by multiplying total LNG carrier propulsion plant (60,000 HP, according to BHP), which equals 44.74 MW, times transit time (in total trip hours) as estimated in a table above.

Cell: H123
Comment: Rick Heede:
It is typical for gas-powered engines to use the boil-off gas (BOG). Under normal conditions this averages 0.12 to 0.15 percent of the carrier's capacity per day of operation. In the case of an LNG carrier with 138,000 m^3 capacity, 0.15 percent per day means a boil-off of 207 m^3 of LNG per day, or, for a 7,908 nmile transit of 16.9 days, a total of 3,422 m^3. This amount is roughly half (54.2 percent) of the fuel consumption of the Wartsila engines operating in gas mode across the Pacific Ocean, and additional LNG will have to be vaporized in transit (see the discussion below using Kuver et al data). While the Wartsila 50DF engines are dual-fueled and the carriers are expected to carry marine diesel fuel onboard, we have NOT assumed any diesel operation mode fo the low estimate.

For the medium emissions estimate, however, we estimate as follows:
Use the boil-off rate as priority fuel input, and supplement with diesel as required. In practice (in this thought experiment), this means that 3,422 m^3 of boil-off LNG is consumed, plus diesel makes up the difference. The result is that less LNG is consumed, more LNG is delivered, and, presumably, more money is made. Total emissions are higher by approximately 17 percent. Küver et al (2002) "Evaluation of Propulsion Options for LNG Carriers," p. 12, shows an example of a 142,000 m3 LNG carrier with boil-off rate of 0.15 percent per day compared to the vessel's LNG requirements at various speeds. A speed of 19.5 knots consumes all BOG, requiring no re-liquefaction and, indeed, no supplementary marine diesel. While this conflicts with our calculation based on BHP-supplied datum of its LNG carrier with a power rating of of 60,000 HP (44.7 MW), we do not correct BHP's assumption and make no adjustments to our calculation.

The high emissions estimate assumes diesel-only mode at an emissions rate of 630 gCO2/kWh, which converts to 11,431 tonnes of CO2 for the 7,908 nm trip and zero net consumption of LNG (assuming that the boil-off gas will be re-liquified or compressed en route).

BHP has stated in its permit application that its carriers will operate in gas-mode to reduce emissions while in Federal waters. The bluewater fuel option will, most likely, be made on financial rather than environmental grounds.

Note: the CSLC's (2006) Revised Draft EIR, p. 2-21: "LNG carriers would have a capacity ranging from 36.5 to 55.5 million gallons (138,000 to 210,000 m 3). Of this volume, an estimated 4 million gallons (15,100 m3) would be consumed by the carrier while in transit for fuel and for maintaining the cold tanks; the remaining 32.5 or 51.5 million gallons (123,000 or 195,000 m 3) would be transferred to the FSRU. LNG carriers would be powered by natural boil-off gas from their LNG cargo, as agreed with the U.S. Environmental Protection Agency (USEPA) (Klimczak 2005). The Applicant has not finalized design specifications for LNG carriers; therefore, the diesel storage capacity for LNG carriers cannot be estimated at this time."

This CSLC and/or BHP estimate is approximately 12 percent higher than calculated here. The CMS estimate for round-trip LNG consumption is 2 * 6,743 m^3 = 13,486 m^3, versus 15,100 m^3 in the CSLC Draft EIR, p. 2-21.

Note: in the "high emissions" example above, the LNG is reliquefied onboard in order to maximise the amount of LNG delivered. See Tore Lunde in the attached report's list of references and Hamworthy, Ltd at www.hamworthy.com. Hamworthy is a leading proponent and systems vendor for this concept. Also see Kuver et al (2002), Larsen & Thorkildsen (2005), and Harper (2002).

Cell: C124
Comment: Rick Heede:
BHP (2005) Cabrillo Permit Application, p. 1-3, Table 1.3-2 and Appendix Table FW-8 (LNG Carrier Vessel Emission Summary, PDF page 112), which cites teh presumed vessel's power rating as 60,000 Brake HP (also, coincidentally, BHP) datum as "from BHP estimates." The BHP calculations only include emissions within US Federal waters. CMS estimates fuel and emissions for the trans-Pacific route.

We take BHP's word for an LNG carrier's power rating (60,000 HP, which converts to 44.74 MW), but this is substantially higher than other similarly-sized LNG vessels recently completed by Mitsubishi, Daewoo, and Samsung, which are in the 137 to 147,000 m^3 range and are powered by 29,000 to 39,500 HP engines. See www.coltoncompany.com/shipbldg/worldsbldg/gas/lngactivity2006.htm

Indeed, any revision to this shipping emissions estimate should anticipate the likelihood that BHP's datum of 60,000 HP either refers to a larger LNG carrier than assumed here, or is in error. Indeed, Kuver et al (2002) "Evaluation of Propulsion Options for LNG Carriers," show the predicted power requirement -- albeit for propulsion only -- of a state-of-the-art LNG carrier of 145,000 m^3 size cruising at 19.5 knots (as we assume here) as ~25 MW, not the 44.74 MW used by BHP.

Cell: D124
Comment: Rick Heede:
1 HP = 0.74570 kW.

Cell: E124
Comment: Rick Heede:
While the BHP permit application does not specify (to our knowledge) the yet-to-be ordered LNG carriers, the document does specify a Wartsila dual-fuel engine for the FSRU. Wartsila supplies power plants to a growing number of LNG shipbuilding orders. These engines are designed to run either or both on natural gas and marine diesel fuel, and can quickly switch fuels. (Even in gas-mode, the engines use about 1 percent diesel fuel for ignition purposes.) The engines -- typically four engines to a large LNG carrier -- generate electricity that power an electric propulsion system. We assume all-gas mode for the trans-Pacific route for the following low emissions estimate, even though it is reasonable to expect considerable use of the higher-emission (but cheaper) diesel fuel mode. All-diesel mode comprises the high estimate, and a mixed-fuel mode determines the medium estimate.

The emission rate for the 50DF series of engines is typically 430 grams of CO2 per kWh (in gas mode; 630 g/kWh in diesel mode); each cylinder generates 950 kW; a typical specification is for three or four 50DFs at each 8,550 to 11,400 kW; the engine series is built in 6 to 18-cylinder models. Note that emissions rates vary by fuel composition, heating value, load, and other factors: we have best-guessed an unspecified ship configuration for illustrative but reasonable circumstances.

See Wartsila 50DF engines at www.wartsila.com, Vaasa, Finland.

Note: the medium estimate assumes that all available boil-off gas is consumed, which supplies approx 54.2 percent of total energy required. The emissions rate shown below is thus a proportional mix of fuel modes.

Cell: H124
Comment: Rick Heede:
Emissions are based on Wartsila engine specifications for the 50DF series (see emissions rate) and total trip energy.

Note: Low emissions estimate is based on gas-only mode, consuming all of the boil-off gas plus additional LNG must be vaporized.

Medium estimate assumes gas plus diesel mode (using all of the boil-off gas), and additional fuel consumed is diesel. Note: ~54 of the required energy is supplied by boil-off gas at 0.15 percent of total LNG carrier capacity per day. See cell notes under "Equiv LNG."

High estimate assumes all diesel fuel mode, with boil-off gas re-liquefied or compressed and stored for delivery. Neither option may be likely, but the purpoe here is to estimate vessel emissions with diesel fuel, regardless of the disposition of the LNG boil-off gas.

Cell: K124
Comment: Rick Heede:
1 tonne of LNG equals 46,467 cf (0.046467 million cf).

Cell: L124
Comment: Rick Heede:
1 tonne of LNG is 2.193 m^3;
1 m^3 of LNG = 0.4560 tonne (I.e, 0.456 the density of water at STP).

Cell: B126
Comment: Rick Heede:

See notes under “Emissions rate” and “Trip emissions” for calculation procedure.

Cell: L126
Comment: Rick Heede:
This figure is lower for the high emissions estimate because only the boil-off gas is used, and the additional fuel requirements are provided by diesel fuel. Hence the higher emissions and “minimum” LNG consumption.

Cell: B130
Comment: Rick Heede:
BHP’s estimate of LNG carrier “reactive hydrocarbons (ROC) as CH4” emissions references US EPA AP-42, Table 3-2-2, and cites an emissions rate of 0.39 grams per brake HP-hr, presumably as uncombusted methane in the fuel stream. We take 90 percent of BHP’s cited emissions factor as the low estimate and 110 percent of BHP’s cited emissions factor as the high estimate.

This row estimates kg of methane per LNG carrier trip from Pilbara LNG plant to Cabrillo Deepwater Port (one way only), and also shows total trip emissions in CO2-equivalent. We use the IPCC GWP factor of CH4 = 23xCO2 (100-year time horizon).

Cell: D137
Comment: Rick Heede:
LNG carrier capacity (assumed as 138,000 m^3) minus the LNG converted to gas and used as propulsion fuel in the Wartsila engines en route to Cabrillo. Naturally, the ship needs to retain approximately an equal amount of LNG aboard for the return trip. In actual operations the carrier will likely carry a larger amount of LNG for the return in order to keep the Moss tanks cold for the re-fill at Onslow, Western Australia. Also, we have not included any LNG or gas consumption while the carrier is being off-loaded -- which takes an estimated 20 hours, including deberthing and turn-around, according to BHP.

This CSLC and/or BHP estimate is approx 12 percent higher than calculated here. The CMS estimate for round-trip LNG consumption is 2 * 6,743 m^3 = 13,486 m^3, versus 15,100 m^3 in the CSLC Draft EIR, p. 2-21. See cell note under Table 8 “Equiv LNG” Cubic meters consumed per one-way trip.

Cell: J137
Comment: Rick Heede:
This summarizes our estimate of total annual emissions of carbon dioxide from BHP’s fleet of LNG carriers serving its proposed Onslow to Cabrillo Deepwater Port project. The emissoins are chiefly from LNG used as fuel in a set of Wartsila 50DF dual-fueled gas engines used to power a vessel’s propulsion drive, plus other ship-board loads such as refrigeration compressors, navigation systems, hotel loads, pumps, motors, lights, heating, hot water, etc. The estimate uses BHP published factors (e.g., the LNG carrier total power rating of 60,000 HP). We also estimate the number of annual berthings by an LNG carrier with nominal capacity of 138,000 cubic meters (and delivering 125,373 m^3): 112 berthings per year, or 2.1 landings per week.

Given the ~7,908 route nautical miles from Onslow, Western Australia, to Cabrillo, at ~19.5 knots, each trip takes 405 hours, or 16.9 days, and consumes 3,075 tonnes of LNG one way, emitting 7,802 tonnes of CO2 per journey (0.987 tonnes of CO2 per nmile). See the calculations and cell notes for details.

Cell: K137
Comment: Rick Heede:
This cell is a sum of estimated emissions of fugitive methane -- in units of carbon dioxide-eqiuvalent per year-- from BHP’s LNG carrier fleet delivering 13.78 million cubic meters of LNG to Cabrillo in a year. See the calculation and cell notes above for details.

Cell: I141
Comment: Rick Heede:
We quantified the amount of natural gas equivalent to the energy inputs to the Pilbara LNG plant in Table 3. Here we estimate the similar natural gas required to fuel the LNG carrier fleet per year. Note that this is an estimate of maximum gas consumption based on the presumption (supported by BHP indications, though not made explicit) that the LNG carriers wiil use LNG boil off gas and indeed operate in all-gas mode in both Federal waters and for the trans-Pacific crossing. As we have stated elsewhere, BHP’s decision will likely be based on minimizing costs, not emissions, and may thus dictate partial diesel mode beyond Federal waters. This would then REDUCE the amount of natural gas used as propulsion fuel, increase total emissions, reduce the number of vessel landings per year (and thus round trips) because more LNG can be delivered per vessel landing. The result is that even fewer trips required by diesel + gas LNG carrier propulsion is not enough to reduce overall shipping emissions.Finally, the total quantity of natural gas produced at Scarborough and liquefied at Pilbara will also be reduced, with cascading savings throughout the supply chain. These considerations have been taken into account to the extent feasible in this brief operational analysis. A more thorough analysis of environmental dispatch would reduce several sources of uncertainty as well as identify numerous opportunties to reduce overall supply-chain emissions while also improving long-term profitability.

Cell: E146
Comment: Rick Heede:
BHP excludes emissions of methane from pipeline leakage (BHP, section 3.6). Tellingly, BHP states that "since fugitive leaks from from the FSRU process equipment will be composed of primarily methane, they are not regulated by permit or source-specific requirements." This suggests a reason for BHP's low emissions levels from the FSRU, namely that they apply factors to fuel combustion equipment, such as tug boats and the large power generators, for uncombusted fuel, i.e., natural gas released to the atmosphere. Thus, natural gas leakage from seals, valves, and other LNG and natural gas handling systems are NOT included.

Note: This omission is estimated in "additions, construction (CH4)" as our high estimate below.

The CSLC Draft Revised EIR (section 4.6.1.4) states that "direct releases of boil-off gas to the atmosphere would take place only during an upset condition." This leaves fugitive methane releases from leaking natural gas handling systems unestimated. It is also possible that such leaks can be brought to zero at an LNG receiving and re-gasification facility.

BHP permit application makes reference to EPA's AP-42 tables, but does not cite specific emissions rates for methane for each combustion source and the EPA default values for methane releases (presumable from uncombusted natural gas).

Also see American Petroleum Institute (2001) Compendium Of Greenhouse Gas Emissions Estimation Methodologies For The Oil And Gas Industry, p. 4-14.

Cell: F146
Comment: Rick Heede:
Methane emissions in tons of methane converted to tons of CO2-equivalent. Note that we use short tons here since we are chiefly listing BHP data.

Cell: G146
Comment: Rick Heede:
This duplicates BHP's (2005) operating emissions summary for the Cabrillo Deepwater operations. We only deduct half of methane emissions from LNG carrier operations as explained in the "LNG carrier" line item below. BHP data are converted to metric tonnes.

Cell: H146
Comment: Rick Heede:
Cabrillo FSRU Startup emissions. BHP estimated emissions from fuel consumption by Wartsila 9L50DF generators and emergency fire pump generator. No emissions are estimated from tug boat operations or use of crew boat. A total of 12.9 tons of methane is included. BHP unit in tons converted to metric tonnes.

Note: Startup emissions are amortized over a 25-year period. See Summary Tables for details.

Note: BHP has not estimated emissions from fuel used in pipelaying and construction activities. CMS does estimate such emissions, albeit quite roughly, given the lack of data. See "Additions to BHP: Vessels and equipment (CO2)" below. This, added to BHP's identified Startup emissions, comprises our high estimate. Note also that we do not include emissions from materials (cement, steel, pipe, copper, petrochemicals) manufacture, assembly, or transportation. We do make a preliminary estimate of emissions from the quantity of steel required for the supply-chain plant (see "Additions: project materials (not included)", but such emissions are too tentative to include in this inventory. Atlantic Train #4 required 14.5 million work-hours (Rick Cape, Atlantic LNG website).

Cell: B147
Comment: Rick Heede:
The FSRU will be 296 m long, 65 m wide, and 50 m high, with a displacement of 200,000 dwt. Moored to a depth of 2,900 feet. Send out pipelines: two 24-inch lines to existing SoCalGas on-shore system. … "The total LNG transfer rate, through the starboard side loading arms, will be approximately 65,000 gallons per minute (gpm). Each LNG carrier berthing, unloading, and de-berthing event will last approximately 20 hours and will occur approximately two to three times per week." The FSRU will host three 56 m diameter (91,000 m^3) spherical Moss tanks with a total storage capacity of 273,000 m^3.

BHP (2005), p. 2-1, 2-2, and 2-3.

Cell: G147
Comment: Rick Heede:
Note: BHP units are in short tons. CMS has converted BHP's emissions to metric tonnes.

Cell: J147
Comment: Rick Heede:
Here we calculate the emissions of methane in the US natural gas industry as a function of total US natural gas consumption for the four major gas industry segments as shown below. Emissions are from EIA (2005a) and (2005b). Year 2004 for both emissions and consumption. These emissions rates are, of course, general, and do not specifically apply to SoCalGas or its customers, or to BHP's supply chain components -- although these factors do help fill in some data gaps in lieu of company data.

Note: CMS applies these methane emission rates in order to estimate supply chain emissions at BHP's Scarborough gas field (using the EIA gas production sector rate) and for emissions related to distributing the gas to SoCalGas customers. Emissions from gas processing and gas transmissions are based on BHP estimates or other metrics shown in the above tables.

Cell: B148
Comment: Rick Heede:
BHP (2005), p. 3-2: "The four lean-burn Wartsila 9L50DF main generator engines will supply the electricity to operate the facility. The Wartsila 9L50DF is a four-stroke lean-burn spark-ignited gas engine. The primary fuel for these engines is natural gas with a small (1%) amount of diesel burned as a pilot fuel. Each of the four units will have power output of 8,250 kilowatts (kW) with an annual estimated operation of 26,280 hours, for a total power plant generating capacity of approximately 25 megawatts (MW)."

Cell: B149
Comment: Rick Heede:
These devices, of which the FSRU operate four units, re-gasify LNG by heating the chilled liquid at a design rate of 115 million Btu/hr. Total annual fuel consumption (though not estimated in the pertinent table, BHP permit, Apppendix A, FSRU Table 9) is 8760 hrs/yr times 115 million Btu/hr with gas at 1007.6 Btu/cubic foot: total gas combusted equals 0.114 million cf per day = 0.9998 billion cf (Bcf) per device, or 4 Bcf in total. This gas consumption (along with other FSRU gas requirements) is entered in Table 1 in order to feed enough gas or LNG through the supply chain to effectively deliver 292 Bcf per year to SoCalGas.

Cell: B150
Comment: Rick Heede:
BHP (2005), p. 3-4: "The crewboat will conduct approximately 2.5 round trips per week. The tug/supply boat will operate once a week to bring supplies to the FSRU and haul black waste from the FSRU back to shore for disposal, and will conduct approximately 2.5 LNG carrier berthings per week. The primary fuel for these vessels will be gasified LNG."

Cell: B152
Comment: Rick Heede:
BHP estimates LNG carrier emissions for ~2.5 vessels arriving (and departing) per week, but only for transit through US Federal waters. Since we estimated LNG carrier emissions for their trans-Pacific voyages, we only include 50 percent of BHP's emissions estimate in order to account for the carriers' energy and emissions during offloading LNG at berth.

Cell: B153
Comment: Rick Heede:
BHP identified small sources, e.g., 3 freefall lifeboats, emergency firepump, etc. BHP also lists a 145,000 gallon diesel fuel storage tank, -- from which no fugitive methane leakage is estimated.

BHP (2005) p. 3-4: "Diesel Storage Tank. Some breathing losses and small amounts of working losses of VOCs will occur from the diesel storage tank. The tank will be kept full but will not be utilized after commissioning except for emergency diesel engine fueling and provision of pilot fuel to the Wartsila engines. The diesel fuel tank will have a capacity of approximately 144,500 gallons."

Cell: J153
Comment: Rick Heede:
Methane emissions from "stationary sources" (in EIA's lingo) refers to fugitive emissions from incomplete combustion of natural gas, chiefly residential and commercial boilers and appliances. Original units in CO2-equivalent, hence our datum (0.476 million tonnes) is divided by 23.

Cell: J154
Comment: Rick Heede:
In the U.S. (2004), methane emissions from natural gas industry -- production, processing, transmission, and distribution -- accounted for 6.64 million tonnes of methane. Using a conversion factor of 0.04228 lb/cf (= 0.019178 kg/cf = 19.178 g/cf); thus 6.64 million tonnes = 346.23 Bcf, which is 1.551 percent of 2004 US natural gas consumption (22,321 Bcf; EIA AER, Table 6.1).

Cell: B155
Comment: Rick Heede:
Emissions of ROCs (reactive organic compounds) are listed in the CSLC Draft EIR (Table 4.6-11) but are not added to the project's construction-phase emissions. It appears that none of BHP's construction fuel-consumption is estimated by either BHP or CSLC (in the latter case, CSLC methane ("ROC") emissions are esimated in the section 4.6.1.3 Regulated Air Pollutant Emissions. CMS thus includes these estimate here as GHG emissions.

These emissions are chiefly from construction activities: primarily from pipelaying, trenching, and related activities using combustion equipment. See the following line item ("Additions to BHP: vessels and equipment").

Cell: E155
Comment: Rick Heede:
CMS adds the methane emissions (listed as ROCs) estimated in CSLC's Table 4.6-11 "Total Air Pollutant Emissions from Project Construction Activities" and a total project emissions of 35 tons of methane.

Cell: B156
Comment: Rick Heede:
BHP has estimated emissions of methane from incomplete combustion of natural gas (derived from re-gasified LNG) used in the equipment categories listed in Table 10. This estimate, as far as we can ascertain, does not include fugitive emissions of methane from leaky pipes, valves, flanges, tanks, seals, and other fuel containment and regasification systems. CMS has not evaluated the legal requirement to estimate additional methane emissions, nor can CMS make an engineering estimate of such emissions without access to company engineering data.

While it is common for conventional natural gas receiving terminals and related systems to leak methane from numerous (non-combustion) sources, both routine venting and fugitive emissions standards are being tightened for FSRUs and FPSOs. BHP has published no data on non-combustion methane emissions from the Cabrillo FSRU.

BHP states that "since fugitive leaks from from the FSRU process equipment will be composed of primarily methane, they are not regulated by permit or source-specific requirements." (BHP permit application, section 3.6).

CMS therefore attributes only one-half of the emissions rate from natural gas processing (0.5 * 28.22 tonnes CH4/Bcf) plus one-tenth of methane emissions from gas distribution and storage (0.1 * 105.73 tonnes CH4/Bcf) as an indicator that a Cabrillo-specific emissions estimate should be made. These emissions rate are applied to total natural gas throughput (292 Bcf delivered to SoCalGas plus 4 Bcf required for Cabrillo operations). The result is shown in US tons to match the BHP presentation units.

In the absence of estimated fugitive methane by BHP and the CSLC, CMS uses the above factors as a preliminary estimate. BHP and/or CSLC may be able to refine this preliminary estimate.

Cell: E156
Comment: Rick Heede:
Emissions of methane from FSRU operations as described in coulmn B: not estimated by BHP.

Cell: B157
Comment: Rick Heede:
CMS estimates additional emissions of carbon dioxide from fuel used during construction of the offshore FSRU , the natural gas pipeline connecting the FSRU to onshore gas utilities, etc.

CMS also estimates emissions of methane from FSRU operations; see line item above. We do not include methane emitted from incomplete combustion of the fuel consumed byconstruction vessels and pieplaying equipment. If CMS had done so, it would be approximately 0.0081 lb CH4 per million Btu (for large-bore diesel engines >600HP), and 0.036 lb CH4 per million Btu (for smaller IC diesel engines). Assuming, roughly, 0.016 lb CH per million Btu and diesel fuel at 128,700 Btu per gallon (LHV; 138,700 at HHV), thus approx. (1.064 million gallons*0.1287 million Btu/gallon) = 0.1369 trillion Btu, and 0.1369 trillion Btu * 0.016 lb CH4 per million Btu = 2,190 lb CH4, i.e., barely 1 ton of methane, and negligible.

Cell: C157
Comment: Rick Heede:
The roughly estimated quantity of carbon dioxide emissions from diesel fuel used in construction vessels and ground equipment (11,905 tons of CO2 (= 10,800 tonnes CO2)) converts to 1.064 million gallons of diesel fuel at 22.384 lbs CO2 per gallon.

Cell: H157
Comment: Rick Heede:
Both the BHP Permit Application and the CSLC Draft EIR present information on a virtual flotilla of dynamically positioned pipelaying vessels (25,000 HP), two anchor handling towing/supply vessels (30,000 HP), crew boat (1,500 HP), a tug and pipe barge (4,000 HP), a construction barge (8,000 HP), a tug (6,500 HP), oceangoing tub (25,000 HP), an exit hole barge tug (4,000 HP), and other smaller vessels. This equipment is anticipated to be operational at various percent loads for days to weeks. Also, for shore crossing and pipeline trenching operations, there will be an armada of forklifts, trenchers, backhoes, dozers, pipebending equipment, dewatering pumps, cement equipment, as well as dump and water and utility and pipestringing trucks.

Source: CSLC (2006), Table 4.6-2 through 4.6-9, Section 4 (Air Quality).

Neither BHP nor CLSC has estimated emissions of greenhouse gases from this equipment's fuel consumption. CMS estimates fuel and emissions very crudely and tentatively as follows:

Assume an average of 50,000 HP of various equipment for an average of 60 days of 12 hrs each.

Estimate emissions by assuming (conservatively) an emissions rate of 500 gCO2/HP-hr.

Crudely, we have 30,000 * 60 * 12 = 21.6 million HP-hrs, * 0.5 kgCO2/HP-hr = 10.8 million kgCO2, or 10,800 tonnes of CO2.

Cell: B158
Comment: Rick Heede:
Consumption of electricity in pipelaying and shore facilities will probably be relatively small and have not been estimated by either BHP or CMS.

Other emissions sources related to the planning, design, construction, and operation of the Cabrillo Deepwater Port -- but not estimated by BHP or CMS -- include air travel from Australia to the US (or shipyards in Asia), commuting to work by construction and operations crews (other than by crew boats, which are included), transportation of pipeline materials, concrete (both cement process and transport), and towing of the FSRU from the shipyard (in Asia?).

Cell: B159
Comment: Rick Heede:
The operational emissions flowing from the processing, freezing, and transportation of 8.1 to 6.4 million tonnes of natural gas annually, depending on where in the supply chain one looks. Emissions related to the mining, smelting, fabrication, assembly, and transportation of millions of tonnes of materials such as cement, aluminum, copper, steel, nickel, insulation, and petrochemicals are not included. CMS considers such emissions potentially part of the full accounting of environmental impacts from the construction and operation of the supply chain, but are not included.

Take steel, for example.
A gas production platform might contain on the order of 20,000 tonnes of steel (and Scarborough is at a depth of 900 meters), a gas pipeline contains ~500 kg per meter (140,000 tonnes from Scarborough to Pilbara), each LNG carrier approx 30,000 tonnes (330,000 tonnes for an 11-vessel fleet), the FSRU about 35,000 tonnes, and a large liquefaction plant embodies on the order of 40,000 tonnes (in cables, pipelines, structural steel, pylons, jetties, tanks, etc). All told, on the order of 0.57 million tonnes of steel. Note: this is a very rough and preliminary approximation.

Delucchi (2003) Appendix H: "The Lifecycle of Materials," p. 84-85, estimates CO2 emissions per tonne of virgin steel at 1,498 kgCO2/tonne (2,996 lb/ton) and recycled steel at 978 kgCO2/tonne (1,956 lb/ton). This includes both process and manufacturing emissions. If we average virgin and recycled emissions we get 1,238 kg of CO2 per tonne of steel, or 1.24 tCO2/tonne. Times 0.57 million tonnes of steel = 0.70 million tonnes of CO2 for steel fabrication. This, of cource, excludes transportation of steel, shipbuilding, platform construction, or pipe manufacturing.

Cell: C161
Comment: Rick Heede:
We quantified the amount of natural gas equivalent to the energy inputs to the Pilbara LNG plant in Table 3 and that required to fuel the LNG fleet in Teble 8. Here we estimate the similar parasitic natural gas required to fuel the Cabrillo regasifaction equipment plus FSRU generators plus tug boats plus the carriers' own generators (to run pumps and hotel loads, etc).

Cell: C162
Comment: Rick Heede:
Total annual natural gas consumed at the Cabrillo FSRU and other equipment converted to tonnes of LNG.

Cell: H173
Comment: Rick Heede:
Not all natural gas made available to the US economy is combusted to carbon dioxide. In 2004, 3.35 percent of total gas supplies were used in non-fuel uses such as fertilizer manufacture, methanol production, and similar end-uses. An analysis of such non-combustion uses reveals that ~90 percent of this carbon is relatively quickly re-emitted to the atmosphere -- but through different pathways and/or with some delay. For example, the produced methanol is burned, and much of the natural gas used in fertilizer production is converted to nitrous oxide via the volatization of nitrogen in fertilizers; N_2O is another greenhouse gas.

EIA(2004) Documentation for Emissions of Greenhouse Gases in the United States 2002, p. 29-30:

Natural gas used for nonfuel purposes include feedstocks for nitrogenous fertilizer production (ammonia NH_3) and other chemical products, especially methanol.

EIA data show half of natural gas used for nonfuel purposes is for fertilizer production and half for other uses. The carbon coefficient is 14.47 kgC/million Btu.

EIA states that the use of natural gas feedstocks to make nitrogenous fertilizers "is considered a non-sequestering use, because the underlying chemical is ammonia (NH_3), which is manufactured by steam reforming of natural gas and reacting the synthesis gas with atmospheric nitrogen, literally leaving the carbon in the feedstock `up in the air.'" Other pathways, e.g., recovering the carbon for urea production, only delays the carbon's release to the atmosphere.

In sum, our analysis concludes that 0.305 percent of total natural gas supply is actually sequestered. This factor is used to estimate the amount of natural gas removed from the combustion pathway and thus NOT emitted to the atmosphere, hence the term "tonnes CO_2 sequestered." The high estimate assumes half the above sequestration rate: 0.305 percent * 0.5.

The formula (low estimate) is thus: total gas delivered to SoCalGas in Bcf/yr * 54.6 tCO_2 per Bcf * 0.00305

The formula (high estimate) is thus: total gas delivered to SoCalGas in Bcf/yr * 54.6 tCO_2 per Bcf * 0.00305 * 0.5

Cell: J173
Comment: Rick Heede:
Per IPPC and US EIA emissions inventory guidelines, the default value for the fraction of natural gas in combustion equipment that is typically not combusted to carbon dioxide is 0.5 percent. This factor is used to estimate the fraction of natural gas sequestered from the atmosphere.

The formula (low estimate) is: total gas delivered to SoCalGas in Bcf/yr * 54.6 tCO_2 per Bcf * 0.005

The formula (high estimate) is: total gas delivered to SoCalGas in Bcf/yr * 54.6 tCO_2 per Bcf * 0.005 * 0.4 (That is, we reduce the uncombusted fraction by 60 percent (from 0.5 to 0.2 percent)).

Cell: K173
Comment: Rick Heede:
After removing the small factors for sequestered non-fuel uses of natural gas and gas not combusted to carbon dioxide, this cell shows the total amount of carbon dioxide emitted by gas consumers in southern California from combustion of the natural gas annually delivered to SoCalGas from LNG regasified at BHP's proposed Cabrillo Deepwater Port. (This formula has been verified.)

Procedural note: This is based on the following: EIA and EPA data on carbon content of natural gas (14.47 kgC per million Btu -- usually expressed as 14.47 TgC/QBtu: 14.47 million tonnes of carbon per quadrillion (10^{15} Btu)).

We use the heat content of "marketed" natural gas at 1,030 Btu per cubic foot.

Formula: 14.47 kgC/million Btu * 1.03 million Btu/1000 cf * 3.664191 CO_2 per C = 54.602 tonnes of CO_2 per Bcf.

Cell: L173
Comment: Rick Heede:
Emissions of carbon dioxide plus methane in CO_2-eq units.

Cell: B174
Comment: Rick Heede:
Table 12 estimates emissions from SoCalGas and the gas utility's customers through: (a) fugitive methane from transmissions and distribution pipelines and related systems, and (b) the combustion of the natural gas marketed (minus the small amounts not fully combusted to carbon dioxide or sequestered through non-fuel uses of natural gas, such as fertilizer production). Since more than 99 percent of the marketed natural gas is converted to carbon dioxide, this item represents the largest single source of supply chain emissions.

Cell: C174
Comment: Rick Heede:
BHP indicates that average LNG re-gasification rate will make 800 million cubic feet of natural gas per day available to SoCalGas.

Cell: D174
Comment: Rick Heede:
Million cubic feet per day times 365 days per year.

Cell: E174
Comment: Rick Heede:
Average methane emissions rates in the US natural gas industry are shown in Table 11. Fugitive methane for major industry sectors are also shown so that emissions rates -- in tonnes of methane per billion cubic feet (Bcf) consumed in the U.S. in 2004 -- can be estimated foreach sector of interest.

The low estimate adds 20 percent of the methane emission rate for transmission and storage, 80 percent of gas distribution, and 80 percent of incomplete combustion, and we apply the resulting 86 tonnes of methane per Bcf to the total amount of gas marketed to SoCalGas customers.

The high estimate adds 25 percent of the methane emission rate for transmission and storage, 100 percent of gas distribution, and 100 percent of incomplete combustion, and we apply the resulting 108 tCH_4/Bcf to the total amount of gas marketed to SoCalGas customers.

Cell: F174
Comment: Rick Heede:
Bcf of natural gas delivered by BHP to SoCalGas times the methane leakage rate = total tonnes of associated methane leakage. Note: this is a generalized estimate. The SoCalGas pipelines and gas handling systems may be less leaky than the US average.

Cell: G174
Comment: Rick Heede:
Total CH_4 leakage times methane's GWP of 23xCO_2, per IPCC TAR, p. 388.

Cell: E177
Comment: Rick Heede:
As a check on the reasonableness of our methane leakage estimate above we calculate the quantity of methane leakage as a percent of the quantity delivered to SoCalGas. 0.48 percent is one-third of the U.S. total methane leakage, which was 1.55 percent in 2004, or 346 Bcf leaked of 22,321 Bcf consumed.

Cell: G183
Comment: Rick Heede:
1 metric tonne = 1.1023 short tons.

Cell: L183
Comment: Rick Heede:
1 metric tonne = 1.1023 short tons.

Cell: B189
Comment: Rick Heede:

Startup emissions do NOT include significant emissions from FSRU materials fabrication, assembly, or transportation on the rationale that such emissions are beyond the defined emissions boundary and are not required to be included by the relevant regulatory rules. The FSRU weighs in at 200,000 dwt (BHP, p. 2-2). CMS has made a very preliminary estimate of steel inputs to the supply chain and related carbon emissions, but CMS not included this estimate in this analysis (see Table 10, line item on “Project materials”).

BHP does address construction emissions in section 3.1, and identify pipelaying vessel energy, assist boats, and onshore drilling rig and trenching equipment. However, these emissions estimates are not quantified in BHP’s application. CMS does so in Table 10, line item “Additions to BHP: vessels & equip. (CO_2)” which estimates the emissions (again, very roughly), chiefly from the consumption of 1.06 million gallons of diesel fuel in construction vessels, pipelaying vessels, trenching for pipelaying, and so forth.

Startup emissions are annualized for a 25-year period. While this may be shorter than total anticipated project lifetime (40 years is mentioned in the CLSC Draft EIR), it is close to the 21.2-year life-expectancy of Scarborough gas field, assuming that the identified 8.0 trillion cubic feet of reserves are produced at an annual rate of 377 billion cf per year detailed in our Table 1. This annual production rate accounts for the gas delivered to SoCalGas by BHP as well as the gas consumed at the Scarborough gas platform, in the 280-km subsea pipeline to the proposed Pilbara LNG plant, for liquefaction and plant use, gas consumption by LNG carriers (boil-off gas), and gas requirements of the Cabrillo FSRU. Without all of these adjustments, the 800 million cubic feet of gas per day deliverable to SoCalGas equals 292 Bcf per year.

Cell: D191
Comment: Rick Heede:
The CMS aggregate methane emissions estimate is 46 percent of the total emissions of methane if solely based on the US CH_4 rate (298 tonnes CH_4/Bcf * 377 Bcf = 112,500 tonnes of CH_4). EIA data; see Table 11 above.

Cell: G200
Comment: Rick Heede:
1 metric tonne = 1.1023 short tons.

Cell: B206
Comment: Rick Heede:
Startup emissions are annualized over a 25-year period. See “Cabrillo Start-Up” in Table 13 for details.

Cell: D208
Comment: Rick Heede:
As with the low methane emissions estimate, this high estimate is considerably lower than methane emissions from the US natural gas industry. The CMS estimate is 73 percent of the total emissions of methane if based on the US CH_4 rate (298 tonnes CH_4/Bcf * 377 Bcf = 112,500 tonnes of CH_4).

Cell: C216
Comment: Rick Heede:
Energy Information Administration (2005a) Emissions of Greenhouse Gases in the United States in 2004, p. x.

Cell: F216
Comment: Rick Heede:
EIA, undated and uncited. Table C3: Summary of State Energy-related Carbon Dioxide Emissions, 1990-2001), milloin metric tonnes of CO_2.

Cell: H218
Comment: Rick Heede:
Supply chain emissions of CO_2 divided by state of California CO_2 (data for 2001).