APPENDIX B.

GREENHOUSE EMISSIONS FOR PALAGUA OILFIELD

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GREENHOUSE EMISSIONS FOR PALAGUA OILFIELD

This document summarizes the estimated greenhouse gas (GHG) emissions for the years 2010 and 2011 in Palagua field located in Colombia.

The current situation must be established in order to estimate emissions and determine opportunities to reduce greenhouse emissions.

For 2010, 20 wells are being drilled. The additional production of the new wells combined with the decline in production of the existing wells will yield a forecasted production of 5,835 bopd (barrels of oil per day), 11,513 bwpd (barrels of water per day) with gas production at 1,785 Mscf/day (thousand standard cubic feet per day). If the excess gas produced is flared, the total emissions will be 59,297 ton eqCO2/year.

However, in order to reduce the greenhouse emissions, selling all the excess gas to a 3 MW plant is being considered. Should this project be viable, the greenhouse gas emission for 2010 is estimated at 32,047 ton eqCO2/year.

The same scenario applies to 2011; 20 more wells will be drilled. The total forecasted oil production of the field is 6,807 bopd, 12,408 bwpd and 2,261 Mscf/day. If the excess production of gas is flared, the greenhouse gas emission will be 72,966 ton eqCO2/year. However, if the sale of excess gas has proven successful, we will continue to sell the excess gas. In other words, the estimated greenhouse gas emission for 2010 would be 33,973 ton eqCO2/year. A summary of the emissions can be found in the table bellow:

Year	2010	2011
Ton eq CO2/year if gas is flared	59,297	72,966
Ton eqCO2/year selling the gas for power generation	32,047	33,973
Estimated ton eqCO2/year	32,047	33,973

The methodologies used for the present calculation were based on the *"COMPENDIUM OF GREENHOUSE GAS EMISSIONS METHODOLOGIES FOR THE OIL AND GAS INDUSTRY"*, published by the American Petroleum Institute in August, 2009.

Other resources used were the *"ENVIRONMENTAL, HEALTH, AND SAFETY GENERAL GUIDELINES"* from the World Bank Group; the *"ENVIRONMENTAL, HEALTH, AND SAFETY GUIDELINES FOR ONSHORE OIL AND GAS DEVELOPMENT"* from the World Bank Group, and its Guidance Notes.

1. Production and consumption data for 2010

CONSUMPTION				
Process	510000	scf/day		
Flared	0	scf/day		
LHV	905	BTU/scf		
Electricity	90000	scf/day		
Drilling rig	Diesel		Gasoline	
Consumption	800	gal/day	200	gal/day
# days per well	14	day/well	14	day/well
# wells	20	well	20	wells
Workover Rig	Diesel		Gasoline	
# workovers/year	175		175	
Consumption	250	gal/day	40	gal/day
# days per workover	2		2	

FIELD DATA			
Oil production	5835	bbl/day	
Water production	11513	bbl/day	
Vehicles	Diesel		Gasoline
Consumption	157.3	gal/day	72.6 gal/day
pick-ups	16	ea	
trucks	6	ea	
Electricity Imports	750000	W-HR/hr	
Number of active wells	120		
Number of separators	4		
Miles of gas pipeline	8.0		
Miles of gas pipeline for transmission	0.31		

* LHV = low heating value

1.1. Fuel data used in Palagua-Caipal Field

FUEL	**Natural gas**	mole %	MW	wt %	# atoms C	Wt%C
	CO2	0.20	44.00	0.53	1	0.14
	CH4	97.15	16.04	94.10	1	70.40
	C2H6	0.68	30.07	1.23	2	0.99
	C3H8	0.20	44.10	0.53	3	0.43
	C4H10	0.10	58.12	0.35	4	0.29
	N2	1.54	28.00	2.60	0	0.00
	Total fuel	**99.87**	**16.56**	**99.35**		**72.25**
		Diesel			**Gasoline**	
	Density	7.07	lb/gal		6.2	lb/gal
	LHV*	5.53E+06	BTU/bbl		4.99E+06	BTU/bbl
	Wt% C	0.8634	lbc/lb diesel		0.866	lbc/lb gasoline

2. Total Greenhouse Gas Emissions 2010

CATEGORY	CO2	CH4	NO2
	ton/year	ton/year	ton/year
COMBUSTION SOURCES			
Stationary devices with 100% efficiency			
Includes: Heaters			
Generator			
Total Facilities:	*10,766*	*0.2*	*2.0E-02*
Generator	*1,900*	*3.9*	*3.5E-03*
Well drilling	*3058*	*5.8E-02*	*1.0E-02*
Workovers	*1117*	*1.9E-02*	*3.0E-03*
Stationary devices with 98% efficiency			
Flares combusted 98%	-	0.0	0.0E+00
non-combusted 2%		0.0	
Total Flares	-	-	*0.0E+00*
Total stationary sources	**16,841**	**4**	**3.7E-02**
Mobile sources			
Diesel vehicles	*643*	*8.8E-03*	*8.8E-04*
Gasoline vehicles	*261*	*1.1E-02*	*2.2E-03*
Total mobile sources	**903**	**0**	**0**
TOTAL COMBUSTION SOURCE	**17,744**	**4**	**0**
INDIRECT SOURCES			
Electricity Imports	*963.2*	*5.5E-02*	*1.8E-01*
TOTAL INDIRECT SOURCES	**963.2**	**5.5E-02**	**1.8E-01**
VENTED SOURCES			
Dehydration processes		*6.9*	
Storage tanks and drain vessels			
Workovers		*0.3*	
Mud degassing	35	67.5	
Process equipment		*1.42E-03*	
Gathering pipeline		4.19E-02	
TOTAL VENTED SOURCES	**34.6**	**74.8**	**0.0**
FUGUTIVE SOURCES			
Oil production		549	
Pipeline gas	6.6E-03	1.16	
Oilwellheads	4.3E-03	0.8	
Separators	1.5E-04	2.6E-02	
TOTAL FUGUTIVE SOURCES	**1.11E-02**	**551**	**0.0**
SUBTOTAL EMISSIONS, tons	18,742	630	2.2E-01
SUBTOTAL EMISSIONS, tons CO2eq		13,238	67

TOTAL EMISSIONS, tons CO2eq/year	**32,047**

3. Production and consumption data for 2011

CONSUMPTION				
Process	495000	scf/day		
Flared	0	scf/day		
LHV	905	BTU/scf		
Electricity	90000	scf/day		
Drilling rig	Diesel		Gasoline	
Consumption	800	gal/day	200	gal/day
# days per well	14	day/well	14	day/well
# wells	20	well	20	wells
Workover Rig	Diesel		Gasoline	
# workovers/year	204		204	
Consumption	250	gal/day	40	gal/day
# days per workover	2		2	

FIELD DATA			
Oil production	6807	bbl/day	
Water production	12408	bbl/day	
Vehicles	Diesel		Gasoline
Consumption	183.3	gal/day	84.6 gal/day
pick-ups	18	ea	
trucks	7	ea	
Electricity Imports	728305.8	W-HR/hr	
Number of active wells	140		
Number of separators	4		
Miles of gas pipeline	17		
Mile gas pipeline for transmission	0.31		

* LHV = low heating value

4. Total Greenhouse Gas Emissions 2011

CATEGORY	CO2	CH4	NO2
	ton/year	ton/year	ton/year
COMBUSTION SOURCES			
Stationary devices with 100% efficiency			
Includes: Heaters			
Generator			
Total Facilities:	*10,449*	*0.2*	*1.9E-02*
Generator	*1,900*	*3.9*	*3.5E-03*
Well drilling	*3058*	*5.8E-02*	*1.0E-02*
Workovers	*1302*	*2.2E-02*	*3.5E-03*
Stationary devices with 98% efficiency			
Flares combusted 98%	-	0.0	0.0E+00
non-combusted 2%		0.0	
Total Flares	-	-	*0.0E+00*
Total stationary sources	**16,709**	**4**	**3.7E-02**
Mobile sources			
Diesel vehicles	*749*	*1.0E-02*	*1.0E-03*
Gasoline vehicles	*304*	*1.3E-02*	*2.6E-03*
Total mobile sources	**1,053**	**0**	**0**
TOTAL COMBUSTION SOURCE	**17,761**	**4**	**0**
INDIRECT SOURCES			
Electricity Imports	*9.4E+02*	*5.3E-02*	*1.7E-01*
TOTAL INDIRECT SOURCES	**9.4E+02**	**5.3E-02**	**1.7E-01**
VENTED SOURCES			
Dehydration processes		*7.5*	
Storage tanks and drain vessels			
Workovers		*0.4*	
Mud degassing	35	67.5	
Process equipment			
Gathering pipeline		9.22E-02	
TOTAL VENTED SOURCES	**34.6**	**75.4**	**0.0**
FUGUTIVE SOURCES			
Oil production		641	
Pipeline gas	6.57E-03	1.16	
Oilwellheads	5.06E-03	0.9	
Separators	1.48E-04	2.62E-02	
TOTAL FUGUTIVE SOURCES	**1.18E-02**	**643**	**0.0**
SUBTOTAL EMISSIONS, tons	18,731	723	2.1E-01
SUBTOTAL EMISSIONS, tons CO2eq		15,176	66
TOTAL EMISSIONS, tons CO2eq/year		**33,973**	

5. CALCULATION EXAMPLE

5.2. COMBUSTION SOURCES

5.2.1. Stationary devices with 100% efficiency

a) Heaters - Process

CO2 EMISSION

$$E_{CO2} = \text{daily consumption} * \frac{1}{\text{molar volumen conversion}} * \text{MW} * \text{Wt\%C} * \frac{44 lb_{CO2}}{12 lb_C}$$

Where:

MW: molecular weight

Wt%C: carbon content of mixture, on mass percent basis;

$$E_{CO2} = 510{,}000 \frac{scf_{fuel}}{day} * \frac{1 lbmol_{fuel}}{379.3 scf_{fuel}} * 16.56 \frac{lb_{fuel}}{lbmol_{fuel}} * 0.72 \frac{lb_C}{lb_{fuel}} * \frac{44 lb_{CO2}}{12 lb_C} * \frac{1 ton}{2000 lb} * \frac{365 days}{1 year}$$

$$E_{CO2} = 10{,}766 \frac{ton_{CO2}}{year}$$

CH4 EMISSION

$$E_{CH4} = \text{daily consumption} * \text{LHV} * \text{EF}_{CH4}$$

Where:

LHV: low heating value

EF_{CH4}: emission factor for CH4

[1]

$$E_{CH4} = 510{,}000 \frac{scf_{fuel}}{day} * 905 \frac{BTU}{scf} * \frac{1.06 x 10^{-6} tonnes_{CH4}}{1 x 10^6 BTU} * \frac{1.10231 ton}{1 tonne} * \frac{365 days}{1 year}$$

$$E_{CH4} = 0.2 \frac{ton_{CH4}}{year}$$

NO2 EMISSION

$$E_{NO2} = \text{daily consumption} * \text{LHV} * \text{EF}_{NO2}$$

Where:

LHV: low heating value

EF_{NO2}: emission factor for NO2

[2]

$$E_{NO2} = 510{,}000 \frac{scf_{fuel}}{day} * 905 \frac{BTU}{scf} * \frac{1.06 x 10^{-7} tonnes_{NO2}}{1 x 10^6 BTU} * \frac{1.10231 ton}{1 tonne} * \frac{365 days}{1 year}$$

$$E_{NO2} = 2.0 x 10^{-2} \frac{ton_{NO2}}{year}$$

[1] Compendium of greenhouse gas emissions methodologies for the oil and gas Industry, American Petroleum Institute, August 2009, page 4-21.

[2] Compendium of greenhouse gas emissions methodologies for the oil and gas Industry, American Petroleum Institute, August 2009, page 4-21.

5.2.2. Mobile sources

The field reports fuel consumption. The carbon content and density of the fuel is found in the decision tree. Ergo, emissions are determined by calculating the two sources.

a) Diesel vehicles

CO2 EMISSION

$$E_{CO2} = \text{daily consumption} * \rho * \text{Wt\%C} * \frac{44 lb_{CO2}}{12 lb_C}$$

Where:

ρ: *densidad*

Wt%C: carbon content of mixture, on mass percent basis;

$$E_{CO2} = 157.3 \frac{gal_{diesel}}{day} * 7.07 \frac{lb_{diesel}}{gal_{diesel}} * 0.8634 \frac{lb_C}{lb_{diesel}} * \frac{44 lb_{CO2}}{12 lb_C} * \frac{1 ton}{2000 lb} * \frac{365 days}{1 year}$$

$$E_{CO2} = 643 \frac{ton_{CO2}}{year}$$

CH4 EMISSION

$E_{CH4} = \text{daily consumption} * \text{LHV} * \text{EF}_{\text{CH4}}$

Where:

LHV: low heating value

EF_{CH4}: emission factor for CH4

$$E_{CH4} = 157.3 \frac{gal_{diesel}}{day} * \frac{1 bbl}{42 gal} 5.53 x 10^6 \frac{BTU}{bbl} * \frac{1.06 x 10^{-6} tonnes_{CH4}}{1 x 10^6 BTU} * \frac{1.10231 ton}{1 tonne} * \frac{365 days}{1 year}$$

$$E_{CH4} = 8.8 x 10^{-3} \frac{ton_{CH4}}{year}$$

NO2 EMISSION

$E_{NO2} = \text{daily consumption} * \text{LHV} * \text{EF}_{\text{NO2}}$

Where:

LHV: low heating value

EF_{NO2}: emission factor for NO2

$$E_{NO2} = 157 \frac{gal_{diesel}}{day} * \frac{1 bbl}{42 gal} 5.53 x 10^6 \frac{BTU}{bbl} * \frac{1.06 x 10^{-7} tonnes_{NO2}}{1 x 10^6 BTU} * \frac{1.10231 ton}{1 tonne} * \frac{365 days}{1 year}$$

$$E_{NO2} = 7.3 x 10^{-4} \frac{ton_{NO2}}{year}$$

b) Gasoline vehicles

CO2 EMISSION

$$E_{CO2} = \text{daily consumption} * \rho * \text{Wt\%C} * \frac{44 lb_{CO2}}{12 lb_C}$$

Where:

ρ: *densidad*

Wt%C: carbon content of mixture, on mass percent basis;

$$E_{CO2} = 72.6 \frac{gal_{gasoline}}{day} * 7.07 \frac{lb_{gasoline}}{gal_{gasoline}} * 0.866 \frac{lb_C}{lb_{gasoline}} * \frac{44 lb_{CO2}}{12 lb_C} * \frac{1 ton}{2000 lb} * \frac{365 days}{1 year}$$

$$E_{CO2} = 261 \frac{ton_{CO2}}{year}$$

CH4 EMISSION

$$E_{CH4} = \text{daily consumption} * \text{LHV} * \text{EF}_{CH4}$$

Where:

LHV: low heating value

EF_{CH4}: emission factor for CH4

$$E_{CH4} = 72.6 \frac{gal_{diesel}}{day} * \frac{1 bbl}{42 gal} 4.99 x 10^6 \frac{BTU}{bbl} * \frac{1.06 x 10^{-6} tonnes_{CH4}}{1 x 10^6 BTU} * \frac{1.10231 ton}{1 tonne} * \frac{365 days}{1 year}$$

$$E_{CH4} = 1.1 x 10^{-2} \frac{ton_{CH4}}{year}$$

NO2 EMISSION

$$E_{NO2} = \text{daily consumption} * \text{LHV} * \text{EF}_{NO2}$$

Where:

LHV: low heating value

EF_{NO2}: emission factor for NO2

$$E_{NO2} = 72.6 \frac{gal_{diesel}}{day} * \frac{1 bbl}{42 gal} 4.99 x 10^6 \frac{BTU}{bbl} * \frac{1.06 x 10^{-7} tonnes_{NO2}}{1 x 10^6 BTU} * \frac{1.10231 ton}{1 tonne} * \frac{365 days}{1 year}$$

$$E_{NO2} = 2.2 x 10^{-3} \frac{ton_{NO2}}{year}$$

5.3. INDIRECT SOURCES

5.3.1. Electricity

Electricity imports

CO2 EMISSION

E_{CO2} = daily consumption * EF_{CO2}

Where:

EF_{CO2} : emission factor for CO2 for Colombia [3]

$$E_{C02} = 750000 \frac{W-h}{h} * \frac{0.133 tonnes_{CO2}}{1x10^6 W-h} * \frac{1.10231 ton}{1 tonne} * \frac{24h}{1day} * \frac{365 days}{1 year}$$

$$E_{C02} = 963.2 \frac{ton_{CO2}}{year}$$

CH4 EMISSION

E_{CH4} = daily consumption * EF_{CH4}

Where:

EF_{CH4} : emission factor for CH4 for Colombia

$$E_{CH4} = 750{,}000 \frac{W-h}{h} * \frac{7.55x10^{-6} tonnes_{CH4}}{1x10^6 W-h} * \frac{1.10231 ton}{1 tonne} * \frac{24h}{1day} * \frac{365 days}{1 year}$$

$$E_{CH4} = 5.5x10^{-2} \frac{ton_{CH4}}{year}$$

NO2 EMISSION

E_{NO2} = daily consumption * EF_{NO2}

Where:

EF_{NO2} : emission factor for NO2 for Colombia

$$E_{NO2} = 750{,}000 \frac{W-h}{h} * \frac{2.44x10^{-5} tonnes_{NO2}}{1x10^6 W-hr} * \frac{1.10231 ton}{1 tonne} * \frac{365 days}{1 year}$$

$$E_{NO2} = 1.8x10^{-1} \frac{ton_{NO2}}{year}$$

[3] Compendium of greenhouse gas emissions methodologies for the oil and gas Industry, American Petroleum Institute, August 2009, page7-13.

5.4. VENTED SOURCES

5.4.1. Oilfield operations

Workovers

CH4 EMISSION

$E_{CH4} = \text{number of workovers} * \text{EF}_{CH4}$

Where:

EF_{CH4} : emission factor for CH4 [4]

$$E_{CH4} = 175 \frac{workover}{year_{2009}} * \frac{0.0018 tonnes_{CH4}}{day} * \frac{1.10231 ton}{1 tonne}$$

$$E_{CH4} = 0.3 \frac{ton_{CH4}}{year}$$

[4] Compendium of greenhouse gas emissions methodologies for the oil and gas Industry, American Petroleum Institute, August 2009, page 4-91.

5.5. FUGUTIVE SOURCES

5.5.1. Oilfield equipment

Oil wellheads

CO2 EMISSION

$$E_{CO2} = \text{number of active wells} * \text{EF}_{CH4} * \frac{0.2 ton moleCO2}{97.2 \text{tonmoleCH4}} * \frac{1 ton moleCH4}{16 ton} * \frac{44 ton CO2}{1 ton moleCO2}$$

$$E_{C02} = 120 wells * \frac{6.63x10^{-7} tonnes_{CH4}}{well * h} * \frac{1.10 ton}{1 tonne} * \frac{0.2 ton moleCO2}{97.2 ton moleCH4} * \frac{1 ton mole}{16 ton} * \frac{44 ton C02}{1 ton moleCO2} * \frac{97.2\% mol_{CH4}}{78.8\% mol_{CH4}} * \frac{24h}{1day} * \frac{365 day}{year}$$

$$E_{C02} = 5.06x10^{-3} \frac{ton_{CO2}}{year}$$

[5]

CH4 EMISSION

$$E_{CH4} = \text{number of active wells} * \text{EF}_{CH4}$$

Where:

EF_{CH4} : emission factor for CH4

$$E_{CH4} = 120 wells * \frac{6.63x10^{-7} tonnes_{CH4}}{well * h} * \frac{1.10231 ton}{1 tonne} * \frac{97.2\% molCH4}{78.8\% molCH4} * \frac{24h}{1day} * \frac{365 day}{year}$$

$$E_{CH4} = 0.9 \frac{ton_{CH4}}{year}$$

5.6. TOTAL EMISSIONS

$$E_{C02} = 18{,}731 ton_{CO2} / year$$

$$E_{CH4} = 723 ton_{CH4} / year$$

$$E_{NO2} = 2.1x10 - 1 ton_{NO2} / year$$

$$E_{CO2} = 18{,}731 \frac{ton_{CO2}}{year} + \left(723 \frac{ton_{CH4}}{year} * \frac{21 ton_{CO2eq}}{1 ton_{CH4}} \right) + \left(2.1x10^{-1} \frac{ton_{NO2}}{year} * \frac{310 ton_{CO2eq}}{1 ton_{NO2}} \right)$$ [6]

$$E_{CO2} = 318{,}731 + 15{,}176 + 66 \frac{ton_{CO2eq}}{year}$$

$$E_{CO2} = 33{,}973 \frac{ton_{CO2eq}}{year}$$

[5] Compendium of greenhouse gas emissions methodologies for the oil and gas Industry, American Petroleum Institute, August 2009, page 6-15

[6] Value determined after Fe de Errata: 45,994 tonCO2eq/year (less than 2% error)