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26. GREENHOUSE GASES AND CLIMATE CHANGE

This chapter provides an assessment of the greenhouse gas emissions associated with the construction and operation of the PNG LNG Project. The chapter, which is a summary of Appendix 25, Greenhouse Gas Impact Assessment, begins by outlining the context of greenhouse gas emissions in Papua New Guinea and its contribution to future global carbon reductions (Section 26.1), then outlines the methods of assessment (Section 26.2), describes the predicted emissions from the project during its life-cycle (Section 26.3), benchmarks the emissions against other liquefied natural gas facilities (Section 26.4), outlines the project design features to maximise energy efficiency (Section 26.5) and then provides an assessment of the residual impact (Section 26.6).

26.1 PNG Context

Papua New Guinea ratified the United Nations Framework Convention on Climate Change in 1993 and the Kyoto Protocol in 2002. A draft Carbon Trade Policy has been developed and (as of May 2007) is awaiting endorsement by Papua New Guinea’s National Executive Council, as is a proposal to create a Designated National Authority (DNA) for the assessment of Clean Development Mechanism (CDM) projects.

In March 2008, Papua New Guinea entered into a cooperative agreement with Australia to reduce greenhouse gas emissions from deforestation and forest degradation: the 'Papua New Guinea–Australia Forest Carbon Partnership'. Nearly two-thirds of PNG's land area is forested (more than 29 million hectares).

Additionally, Papua New Guinea’s rainforests are being targeted for carbon emission reduction schemes under the reduced emissions from deforestation and degradation (REDD) mechanism (see Section 24.3.8, Cumulative Impacts Upstream Summary and Appendix 7, Forestry Impact Assessment). The REDD mechanism is aimed at offsetting carbon emissions by protection of forest that would otherwise have been degraded by logging or other means.

CO_2 emissions data from PNG fossil fuel combustion are presented in Figure 26.1. Emissions have increased from 2.58 Mt in 2001 to 4.35 Mt in 2005. As a comparison, Australia’s CO_2 emissions from fossil fuel combustion increased from 367 Mt in 2001 to 407 Mt in 2005. PNG contributes a minor proportion of greenhouse gas emissions from fossil fuel combustion: 0.04% of emissions from the Asia/Oceania region and 0.02% of global emissions.

26.2 Greenhouse Gas Assessment

26.2.1 Methods of Assessment

The assessment of the greenhouse gas emissions associated with the construction and operation of the PNG LNG Project involved:

- Identification of the sources of greenhouse gas emissions from construction and operations.
- Calculation of the quantities of greenhouse gases from these sources.

Figure

26.1 PNG CO_2 emissions from fossil fuel combustion (1980 to 2005)

- Analysis of expected greenhouse gas emissions and comparison against total PNG emissions, emission intensities at other LNG plants and other energy sources.
- Identification of emission abatement measures currently planned as part of the PNG LNG Project.

Emissions of greenhouse gases were calculated in accordance with methods provided by the Australian Greenhouse Office (AGO, 2006) and Australian Department of Climate Change, which are generally in accordance with the World Business Council for Sustainable Development/World Resources Institute Greenhouse Gas Protocol.

26.2.2 Nature of Greenhouse Gases Included

Consistent with the Kyoto Protocol, efforts by industrialised countries to minimise greenhouse gas emissions have concentrated on six key greenhouse gases. Of these, only carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are usually applicable to natural gas production and combustion.

Although representing only a small proportion of total greenhouse gas emissions, emissions of methane and nitrous oxide have been estimated using the latest emission factors provided by the Australian Greenhouse Office for natural gas combustion by gas turbines, combined with the specific gross calorific value and density of the various fuel gases expected for the PNG LNG Project.

Estimated greenhouse gas emissions include only Scope 1[1] emissions, which are direct emissions that occur from sources that are owned or controlled by the company, for example, emissions from combustion of natural gas in the production of LNG, and combustion of diesel by vehicles and mobile equipment during the construction and operation of the project.

There are no Scope 2 emissions associated with the project and reporting of Scope 3 emissions is an optional category that allows for the treatment of all other indirect emissions. Scope 3 emissions are excluded from the emission calculations used to determine compliance with Kyoto Protocol commitments and are generally excluded from a country's national emissions inventory to avoid double-counting of emissions. However, Scope 3 emissions associated with the total production of LNG over the life of the project have been calculated to benchmark this fuel to other fossil fuel energy sources (see Section 26.4, Benchmarking of Greenhouse Gas Emissions).

26.2.3 Fuel Gas Emission Factors

Gas compositions are expected to vary during the 30-year life of the project and between different stages of the gas processing. Concentrations of methane, ethane, propane, butane, pentane, nitrogen dioxide and carbon dioxide, as well as the energy content, are the main variables considered. Four gas compositions have been identified as being representative of the gas

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[1] Scope 1 emissions, which are direct emissions that occur from sources that are owned or controlled by the company; Scope 2 emissions include those resulting from the generation of purchased electricity that is consumed by the company; Scope 3 emissions are a consequence of the activities of the company, but occur from sources not owned or controlled by the company.

compositions expected to be experienced during the life of the project. These compositions were used to calculate variations in emission factors during the 30-year project life, as shown in Table 26.1. The methods for calculating the gas-specific emission factor from the gas composition data are in accordance with the Australian Greenhouse Office's Generator Efficiency Standards Technical Guidelines 2006 (AGO, 2006).

The fuel gas to the Hides Gas Conditioning Plant has been classified into two broad gas composition streams (i.e., years 1 to 10 and 21 to 30, and years 11 to 20) reflecting variations in wellstream product over different phases of the project. Emissions of greenhouse gases were calculated for each year of operation based on the consumption of a particular gas composition at quantities provided by the proponent.

Juha Production Facility is expected to receive 'Juha Case 4' gas for its entire operational life between years 10 and 23.

The 'LNG Plant Fuel' composition and emission factors have been used for the entire life of the LNG plant. The calculations are exclusive of CO_2 abatement as none have been established.

Table 26.1 Gas combustion emission factors

Gas Specification	CO_2 Emission Factor (kg CO_2-e/kg fuel)[2]	CH_4 Emission Factor (kg CO_2-e/kg fuel)	N_2O Emission Factor (kg CO_2-e/kg fuel)	Emission Factor (kg CO_2-e/kg fuel)
Hides Case 10 (Yr 1-10, 21-30)	2.72	0.0081	0.0015	**2.73**
Hides Case 7 (Yr 11-20)	2.66	0.0078	0.0014	**2.67**
Juha Case 4 (Yr 10-23)	2.54	0.0074	0.0014	**2.55**
LNG Plant Fuel (Yr 1-30)	2.56	0.008	0.0015	**2.57**

26.2.4 Emission Sources

Sources of greenhouse gas emissions associated with the construction and operation of the PNG LNG Project (see Chapter 2, Producing the Gas, Chapter 4, Producing and Exporting the LNG and Section 20.8, Air Quality) and included in this assessment are listed below:

- Hides Gas Conditioning Plant:
  - Diesel[3] used during construction.
  - Gas used in pipeline compressors, booster compressors and turbo generators.
  - Vent gas from incineration/flaring.

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[2] CO_2-e – carbon dioxide equivalent.

[3] Note: where practicable, diesel-powered equipment will use low-sulfur diesel fuel (see Section 18.8.3, Mitigation and Management Measures, and Section 20.7.3, Mitigation and Management Measures).

  - Diesel used in essentials generator, firewater pump and industrial-area incinerator.
  - Gas used for hot–oil-fired heater.

- Juha Production Facility:
  - Diesel used during construction.
  - Gas used by rich gas compressor turbine generators, and TEG regeneration.
  - Flaring.
  - Diesel used by essentials generator.

- LNG Plant:
  - Diesel used during construction.
  - Gas used by gas turbines for power generation and refrigerant compressors.
  - Gas used by heaters/boilers.
  - Flaring of natural gas (including the pilot flare and fugitive emissions) and the acid gas incinerator (includes combusted acid gas or reservoir CO_2).

- Shipping (between the pilot station and the LNG Facilities) which includes natural gas, diesel or marine bunkers, heavy fuel oil and marine diesel oil used by ships and tugs for transport of the LNG and condensate product. Only those shipping activities between the pilot station at the entrance to Caution Bay and the LNG Facilities site are included. Emissions associated with shipping on the high seas to international markets would constitute a Scope 3 emission and are excluded.

The effects of clearing vegetation for the pipelines and facilities (which result in emissions from decomposing vegetative matter) have not been calculated and are excluded from this assessment. Methods for measuring and calculating emissions from deforestation in Papua New Guinea are yet to be developed. As noted earlier, Papua New Guinea and Australia recently entered into a cooperative agreement to address this and other issues relating to greenhouse gas emissions from deforestation.

Leaks and accidental releases of gas from gas pipelines, known as fugitive emissions, are considered to only occur under rare, abnormal conditions and would represent a very low proportion of total greenhouse gas emissions. This view is supported by the Australian Greenhouse Office (AGO, 2006) in their guidelines, which assume emissions from these sources to be zero due to the following facts:

- The gas transmission system is very new and is built and maintained to high quality standards, as evidenced by the extreme rarity of accidental releases.

- Most lines are built with isolating valves at regular intervals along the line, limiting the quantity of gas released in the event of a line rupture.

The assumption of zero emissions from these sources is also expected to apply to the PNG LNG Project.

26.3 Greenhouse Gas Emissions

26.3.1 Emissions from Project Construction

It is anticipated that the PNG LNG Project will be constructed over four years; two years for the upstream facilities and four years for the LNG Facilities site (see Figure 1.3). Greenhouse gas emissions associated with construction arise through the combustion of diesel by plant and equipment. An estimated 174,100 kL of diesel is expected to be consumed during the construction of the project. Although the actual equipment and fuel use may vary from these estimates, it is important to note that diesel consumption will comprise only a very small proportion of total greenhouse emissions for the project. The emission factor for diesel provided by the Australian Department of Climate Change (Appendix 25, Greenhouse Gas Impact Assessment), which was used to calculate greenhouse gas emissions from these activities, is 2.7 t CO_2-e/kL.

Table 26.2 below shows the resulting emissions expected during the construction of the upstream and LNG Facilities.

Table 26.2 Emissions summary for construction

	Annual Emissions (Mt CO_2-e)				
Stage	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Total**
Upstream (diesel)	0.083	0.118	0.083	0.047	0.331
LNG Facilities site (diesel)	0.054	0.054	0.054	0.005	0.217
Total	**0.137**	**0.172**	**0.137**	**0.101**	**0.548**

26.3.2 Emissions from Upstream Facilities Operations

Emissions associated with the upstream facilities essentially include the operation of the Hides Gas Conditioning Plant and the Juha Production Facility. Emissions from the operation of the Hides, Angore and Juha wellfields are expected to be insignificant relative to emissions from the Hides Gas Conditioning Plant and Juha Production Facility and have therefore not been included in the assessment.

Likewise, project-related upgrades to facilities supporting associated oil field gas reserves (i.e., Kutubu, Agogo, Gobe and Moran) will not materially alter existing emissions at these facilities and are therefore not included in this assessment.

Table 26.3 shows the total project emissions for each of the upstream emission sources identified in Section 26.2.4, Emission Sources. Annual consumption of fuel gas is assumed to be constant; emissions of greenhouse gases vary slightly due to changes in the gas composition.

The majority (90%) of total upstream emissions will be generated from the Hides Gas Conditioning Plant. It is currently anticipated that the Juha Production Facility will only be operating for years 10 to 23. Annual emissions from the Hides Gas Conditioning Plant range from 0.375 Mt CO_2-e to 0.610 Mt CO_2-e, with the majority being generated through the consumption of gas by pipeline and booster compressors.

Table 26.3 Emission summary for upstream facilities

Hides Gas Conditioning Plant	Maximum Annual Emissions (Mt CO_2-e)
Pipeline compressors	0.300
Booster compressors	0.213
Turbo generator	0.064
MEG vent gas incinerator	0.00978
High-pressure/low-pressure flare	0.0151
Essential diesel generator	0.000020
Hot–oil-fired heater	0.000000002
Diesel fire water pump	0.000003
High-temperature industrial incinerator	0.0109
Hides Gas Conditioning Plant Total	**0.610**
Juha Production Facility	
Rich gas compressor	0.112
Turbine generator package	0.0209
TEG regeneration package	0.00505
High-pressure/low-pressure flare	0.000309
Essential diesel generator	0.00629
Juha Production Facility Total	**0.144**
Total	**0.754**

Emissions from the Juha Production Facility range from 0.116 Mt to 0.144 Mt CO_2-e per annum, with the rich gas compressor being the highest contributor.

26.3.3 Emissions from LNG Facilities Site

The LNG liquefaction train(s) will process 1,133 kSm^3/hr of feed gas. The LNG train comprises a medium-pressure and a low-pressure propane cooler, a scrub column, the main cryogenic heat exchanger, and an endflash section. The gas turbine generators supply the LNG Plant power requirements. Emissions estimates conducted for both frame and aero-derivative turbine technologies are presented in Table 26.4, as both were considered.

Table 26.4 LNG Facilities emissions

Type of Technology	Maximum Total Emissions (Mt CO_2-e)	
	Frame Turbine	**Aero-derivative**
Power generation - gas turbine generators	12.52	10.25
Propane refrigerant compressors	19.22	14.19
Mixed refrigerant compressors	25.74	21.28
Acid gas incinerator	6.30	6.30
Heaters/boilers	5.66	5.66
Desalination plant	0.12	0.12
Miscellaneous[1]	0.74	0.74
Total	**70.30**	**58.54**

[1] Low-pressure fuel gas for flare header purging, flare pilots and incinerators.

As Table 26.4 shows, there is a considerable saving in greenhouse gas emissions available from using the newer, aero-derivative technology rather than the widely used frame-turbine technology. The PNG LNG Project has conducted a comparison of the two technologies and has chosen to proceed with the aero-derivative technology due to its superior fuel efficiency.

Acid gas from the acid gas removal units will be incinerated, which will also result in greenhouse gas emissions. The quantity of acid gas to be incinerated is largely determined by the CO_2 content of the feed gas. The CO_2 content of the feed gas ranges between 0.7 and 2% and is relatively low compared to other LNG projects around the world (Table 26.5).

The small quantities of ‘miscellaneous’ emissions result from the consumption of low-pressure fuel gas for flare header purging, flare pilots and incinerators. Flares will only be operating during upset conditions or during start-up and shutdown. The plant design basis does not anticipate any continuous flaring of hydrocarbons during normal operations [M167]. It is not possible to calculate the annual flare gas throughput as it depends on a number of parameters, such as number of emergency and planned shutdowns per year. The only continuous emissions from the flares will be the flare header purge gas and pilot gas. These quantities are minimal, but have been included in calculation of project greenhouse gas emissions.

LNG and condensate will be shipped to customers worldwide from the port facilities to be constructed at the LNG Facilities site. Greenhouse gas emissions from these shipping activities to the boundary of the pilot station at the entrance to Caution Bay have been estimated, based on the predicted fuel consumption by ships and tugs and the estimated number of visits, and these are presented in Table 26.6.

Table 26.5 Benchmarking global LNG facilities

Project	Capacity (MTPA)	Aero-derivative Turbines		Geosequestration	Waste Heat Recovery		Mono-diethanolamine[1]	Reservoir CO_2 mol%
		Process	Power		Process	Power		
Darwin, LNG	3.7	Y	N	N	Y	N	Y	6.0
Karratha OGPT1-T4	7.5 to 8	N	N	N	Y	N	Y	2.5
Qatargas, Qatar	4.8	N	N	N	N	N	N	2.1
RasGas, Qatar	6.4	N	N	N	N	N	N	2.3
Atlantic, Trinidad and Tobago, LNG	15.1	N	N	N	Y	N	N	0.8
Gorgon, Western Australia	8	N	N	Y	Y	N	Y	14
Karratha OGP T4	4.5	N	Y	N	Y	N	Y	2.5
Nigeria LNG	6.1	N	N	N	N	N	Y	1.8
PNG LNG	6.3	Y	N	N	Y	N	Y	0.7 to 2.0
Pluto LNG, Western Australia	4.8	N	N	N	Y	N	Y	2.0
Oman LNG	6.9	N	N	N	N	N	N	1.0
Snohvit, Norway	4.2	N	Y	Y	Y	N	Y	8.0

[1]Mono-diethanolamine is used to remove carbon dioxide from gas streams.

Table 26.6 Shipping emissions

Source	Maximum Annual Emissions (Mt CO_2-e)
Shipping (LNG carriers)	0.0166
Tugs (for LNG carriers)	0.0233
Shipping (condensate tankers)	0.000223
Tugs (for condensate tankers)	0.00304
Total	**0.0432**

It is planned that LNG carriers will make 95 port calls per annum, while the condensate carriers will make 17 port calls per annum. When an LNG carrier or condensate tanker calls at the port facility, tugs will also be required for:

- Escorting the carrier from the pilot station to the jetty.
- Assisting the carrier with mooring.
- Standing by while loading.
- Assisting with unmooring.
- Escorting the carrier back out to the pilot station.

For the purposes of impact assessment, it is assumed that the tugs' home port would be at Motukea Island (see Figure 7.5). With regard to greenhouse gas emissions, this would be the worst-case scenario compared to the tugs' home port being at the LNG Facilities site, as it is the furthest tugs would need to travel for the project.

26.3.4 Total Project Greenhouse Gas Emissions

The total emissions over the expected 30-year life of the PNG LNG Project are summarised in Table 26.7. The LNG Plant itself is expected to contribute 76% of total project emissions.

Table 26.7 Project emissions

Activity	Maximum Annual Emissions (Mt CO_2-e)	Total Emissions (Aero-derivative Option) (Mt CO_2-e)	% of Total Annual Emissions
Construction	-	0.547	0.71
Hides Gas Conditioning Plant	0.610	15.426	19.93
Juha Production Facility	0.144	1.618	2.09
LNG Plant	2.340	58.527	75.60
Shipping	0.043	1.296	1.67
Total Emissions	**3.136**	**77.414**	**100.00**

26.3.5 PNG Total Emissions Context

The estimated maximum annual emissions over the 30-year life of the project are presented in Figure 26.2, which also compares emissions reductions from the use of aero-derivative rather

Figure

26.2 PNG LNG Project estimated annual emissions

than frame turbines. The maximum annual greenhouse gas emissions from the project (3.136 Mt CO_2-e) are predicted to be 42% of total greenhouse gas emissions from fossil fuel combustion in Papua New Guinea from 2005 (which represent the most recent emissions data available).

26.4 Benchmarking of Greenhouse Gas Emissions

26.4.1 Comparison with Other Fossil Fuels

The emission factor for eventual PNG LNG Project combustion has been calculated at 53.87 kg CO_2-e per GJ, based on the specific gas composition data. This compares favourably to the emission intensity of other fossil fuels commonly used for stationary energy, as listed below (in kg CO_2-e per GJ):

- Brown coal – 93.2.
- Black coal – in the order of 91.2.
- Fuel oil – 73.1.
- Diesel – 69.5.

26.4.2 Direct and Indirect Emissions

These emission factors represent the Scope 1 emissions as defined within the Greenhouse Gas Protocol (i.e., the direct emissions from the combustion of the fuel on site). However, when comparing the greenhouse gas intensities of different fuels, it is important to also consider the emissions associated with extracting, refining and transporting of those fuels, i.e., Scope 3 emissions under the Greenhouse Gas Protocol.

The PNG LNG Project is expected to produce 8,610 petajoules (PJ) of LNG over its 30-year life. The estimated greenhouse gas emissions from this output of approximately 88.1 Mt CO_2-e equates to 10.23 kg CO_2-e per GJ of LNG. Therefore the full fuel emissions factor for customers of the PNG LNG Project will involve Scope 1 emissions of 53.87 kg CO_2-e per GJ, plus Scope 3 emissions of 10.23 kg CO_2-e per GJ, a total of 64.1 kg CO_2-e per GJ. Figure 26.3 presents this against the full fuel emission factors for other stationary energy sources as presented in the Australian Department of Climate Change NGA Factors (2008, as cited in Appendix 25, Greenhouse Gas Impact Assessment). Although the Scope 3 emissions for LNG are higher than for most other fuels due to the energy associated with the liquefaction of the natural gas, the overall full fuel cycle emissions per gigajoule are still lower than other common energy sources. For example PNG LNG Project greenhouse gas emissions on a full fuel cycle basis would be 33% lower than the black coal energy equivalent.

26.4.3 Other LNG Developments

Figure 26.4 indicates the greenhouse gas intensities of recent LNG developments. All of the benchmarked LNG developments have been constructed within the last six years, with the exception of Gorgon (now in construction) and the Karratha Gas Plant in Australia.

This data compares emissions from only the LNG Plant and does not include emissions from gas extraction or processing prior to reaching the LNG Plant (i.e., it does not include emissions from Hides Gas Conditioning Plant or Juha Production Facility).

Figure

26.3 Emissions benchmarking of fossil fuels

Figure

26.4 Emissions benchmarking of LNG facilities

Greenhouse gas intensity refers to the volume of greenhouse gases emitted per unit of energy or economic output. The greenhouse gas intensity (the volume of greenhouse gases emitted per unit of energy or economic output) of the facilities is influenced by a range of internal (technology) and external (environmental/geological) factors. The main factors that have a significant impact on greenhouse efficiency are the reservoir CO_2 content (a higher CO_2 content equates to more CO_2 removal prior to liquefaction) and ambient temperature (compressor efficiency is favoured by cooler temperatures).

Technological and process factors that influence greenhouse gas intensity include:

- Choice of liquefaction technology.
- Power generation, i.e., choice of energy source, technology and configuration.
- Waste heat recovery.
- Acid gas removal process.

Information on some of these influencing factors is presented in Table 26.5.

26.5 Project Design

The proposed PNG LNG Project includes a number of design features and industry good practice initiatives that will ensure that energy efficiency is maximised and greenhouse gas emissions are minimised (see Chapter 29, Summary of Management Commitments). Waste heat will be recovered and used as an energy source at the Hides Gas Conditioning Plant and the LNG Plant, which will reduce fuel gas consumption and greenhouse gas emissions that would otherwise be associated with providing an alternative heat source (e.g., via a gas-fired heater or boiler).

- At the Hides Gas Conditioning Plant, waste heat from the exhaust of the pipeline compressor gas turbines will be used to provide heat to the thermal-fluid–based, hot-oil system [M168] (see Section 2.7.1.1, Gas Processing).

- Similarly at the LNG Plant, waste heat recovery units will utilise heat from the exhaust from the aero-derivative turbines driving the two propane refrigeration compressors to provide the main source of heat to the hot-oil system [M48] (see Section 4.2.3.1, Hot Oil System).

Discussion of the assessment of the potential to geosequester CO_2 from the raw gas stream and arising from gas combustion at project facilities is discussed in Section 7.9, Reservoir Carbon Dioxide.

Esso will also consider a review of the REDD mechanism as a means of reducing CO_2 emissions by limiting potential indirect forest degradation and deforestation along the pipeline right of way [M114] (see Section 24.3.8, Cumulative Impacts Upstream Summary and Appendix 7, Forestry Impact Assessment).

26.6 Residual Assessment

The PNG LNG Project is expected to generate greenhouse gas emissions to a maximum of 3.1 Mt CO_2-e per annum. Over the 30-year life of the project, total emissions are estimated at 77 Mt CO_2-e. The low level of CO_2 in the feed gas and the choice of aero-derivative technology has resulted in the greenhouse gas emissions overall for the project comparing favourably with other similar LNG operations around the world.

The project will be a contributor to Papua New Guinea’s total emissions. However, in a global context, the production and export of LNG from this project will represent a reduction in global greenhouse gas emissions compared to if customers were to use other fossil fuel sources for their energy requirements (e.g., coal, fuel oil or diesel). The LNG from this project is also likely to have a lower greenhouse gas intensity than most other LNG projects around the world when the emissions associated with LNG production are considered.