Pluto LNG Project
Greenhouse Gas Abatement Program

Date: 20/6/11

Status: Rev 2

Table of Contents

1 Executive Summary

1.1 The Proponent

Woodside is the operator of the Pluto LNG Project, located on the Burrup Peninsula, and is also the owner of the project, along with joint venture participants Kansai Electric Power Australia Pty Ltd and Tokyo Gas Pluto Pty Ltd.

Woodside operates Australia's biggest resource development, the North West Shelf Venture (NWSV) in Western Australia, a project that produces approximately 40% of Australia’s oil and gas.

Woodside is committed to minimising greenhouse gas emissions from the company’s production of energy products. This commitment is enunciated through the company Greenhouse Policy.

References in this document to “Woodside” may be references to Woodside Petroleum Ltd or its applicable subsidiaries.

1.2 Purpose and Scope of the Greenhouse Gas Abatement Program

In accordance with Ministerial Statement No 757 Woodside is required to prepare a Greenhouse Gas Abatement Program:

- to ensure that the plant is designed and operated in a manner which achieves reductions in ‘greenhouse gas’ emissions as far as practicable
- to provide for ongoing ‘greenhouse gas’ emissions reductions over time
- to ensure that through the use of best practice, the total net ‘greenhouse gas’ emissions and/or ‘greenhouse gas’ emissions per unit of product from the project are minimised
- to manage ‘greenhouse gas’ emissions in accordance with the Framework Convention on Climate Change 1992, and consistent with the National Greenhouse Strategy.

The scope of this Greenhouse Gas Abatement Program describes Woodside’s approach of greenhouse gas management for Train 1 only. Construction of Train 2 may occur at a later stage depending on exploration success and/or the opportunity to process third party gas. This document will be updated to incorporate Train 2 prior to commencement of construction.

The primary purpose of the program is to identify opportunities in which the Pluto LNG Project can minimise its greenhouse footprint.

The major sources of greenhouse gas emissions for Pluto LNG Project (approximately) are:

- gas turbines for liquefaction (50%)
- power generation (30%)
- reservoir CO_2 (15%)

Reservoir emissions are proportional to the CO_2 content of the feed gas, which for the Pluto LNG Project is estimated at 2 mol% and amount to approximately 0.24 million tCO_{2e} per annum. Based on the operation of the first of two LNG trains, with an expected production of 4.3 Mtpa of LNG and onshore infrastructure, the total greenhouse emissions are anticipated to be in the order of 1.61 Mtpa $CO_{2\text{-}e}$.

Opportunities for minimising the greenhouse footprint of the Pluto LNG Project to and beyond ‘business as usual’ have been identified, evaluated and implemented where economically and technically feasible, or strategically justified, within the context of a carbon-copy North West Shelf Venture (NWSV) Train 5 model.

With both the technical and market abatement measures implemented for the Pluto LNG Project, the efficiency of the plant with respect to greenhouse emissions is approximately 0.31

$tCO_{2\text{-}e}$ per tonne of LNG produced, making it the most greenhouse friendly LNG plant operating in Australia.

In alignment with the Greenhouse Gas Policy and Environment Policy, the Pluto LNG Project will seek further opportunity to abate greenhouse gas emissions throughout the development and operations of the asset.

2 Introduction

The Woodside Pluto Liquefied Natural Gas (LNG) Project is located immediately south of the Karratha Gas Plant (KGP) on the Burrup Peninsula, Western Australia. In 2007, Woodside secured both State (Western Australian) and Commonwealth environmental approvals for the following key components of the approved Pluto LNG Project (Ministerial Statements No. 733 and 757, and EPBC 2005/2391 and 2006/2968):

- offshore subsea wells, an unmanned riser platform and associated subsea infrastructure
- a gas trunkline, approximately 190 km in length, linking the offshore Pluto gas field (WA-34-L) with the onshore gas processing facilities
- an onshore gas processing plant, producing up to 12 million tonnes of LNG per annum (Mtpa) from two LNG trains (Trains 1 and 2) located on Industrial Lease B (Site B) on the Burrup Peninsula
- gas storage and export facilities for LNG and condensate located on Industrial Lease A (Site A) on the Burrup Peninsula
- up to 14 million cubic metres of associated capital dredging and spoil disposal works.

The project is being established in a staged process. The first phase is the construction of Train 1 and associated supporting infrastructure. Construction of Train 1 to a design capacity of 4.8 Mtpa is nearing completion and expects to be delivering first cargos of LNG in March 2012. Work required to sanction construction of Train 2 is being progressed as a priority, however this will occur only following the assurance of sufficient gas supply. For this reason, the scope of this Greenhouse Gas Abatement Program describes Woodside's approach of greenhouse gas management for Train 1 only.

This document will be updated at a later stage (prior to Train 2 commissioning) when further gas supply, compositional analysis and design information is known for the Train 2 development.

2.1 Objectives

A condition of environmental approval by the State Minister is to prepare a Greenhouse Gas Abatement Program for the project as set out in Ministerial Statement No. 757. Woodside supports the global effort to reduce greenhouse gas emissions and actively designs and operates its facilities to minimise greenhouse emissions, as far as practicable.

This document provides information and sets out an approach to achieve the following key objectives in accordance with condition 12-1 of Statement No. 757:

- to ensure that the plant is designed and operated in a manner which achieves reductions in greenhouse gas emissions as far as practicable
- to provide mechanisms for identifying and evaluating emission improvements, the implementation of these improvements, where practicable, in an effort to minimise emissions during operations
- to ensure that through the use of best practice, the total net greenhouse gas emissions and/or greenhouse gas emissions per unit of product from the project are minimised
- to manage greenhouse gas emissions in accordance with the *Framework Convention on Climate Change 1992*, and consistent with the *National Greenhouse Strategy*.

2.2 Structure of this Program

This Greenhouse Gas Abatement Program for the Pluto LNG Project comprises the following elements:

- description of the project (**Section 3**)
- Woodside's policy and approach for greenhouse gas abatement (**Section 4**)

- benchmarking of the Pluto LNG Project's emission profile against profiles of other existing and proposed operations located in Australia and world-wide (**Section 5**)
- description of the adopted greenhouse mitigation measures in the design of the Pluto LNG Project (**Section 6**)
- the calculation of the emission profile for Train 1 based upon adopted design measures (**Section 7**)
- description of future opportunities for further greenhouse mitigation (**Section 8**)
- description of greenhouse gas offsets committed to by Woodside (**Section 9**)
- targets and mechanisms for monitoring, auditing and reporting (**Section 10**)
- the approach for a greenhouse gas performance improvement plan (**Section 11**)
- mechanisms for management review of this document (**Section 12**).

The document addresses the full requirements of condition 12-1 as shown in Table 2-1.

Table 2-1 Compliance with Ministerial Condition 12-1

Ref No.	Component of Ministerial Condition 12	Relevant Section in Document
1	Calculation of the "greenhouse gas" emissions associated with the proposal as advised by the Environmental Protection Authority.	Section 7
2	Specific measures to minimise the total net "greenhouse gas" emissions and/or the "greenhouse gas" emissions per unit of product associated with the proposal using a combination of "no regrets" and "beyond no regrets" measures.	Sections 6, 8 and 9
3	The implementation and ongoing review of "greenhouse gas" offset strategies with such offsets to remain in place for the life of the proposal.	Sections 8.3.1 and 9
4	Estimation of the "greenhouse gas" efficiency of the project (per unit of product and/or other agreed performance indicators) and comparison with the efficiencies of other comparable projects producing a similar product, both within Australia and overseas.	Sections 5 and 7
5	Implementation of thermal efficiency design and operating goals consistent with the Australian Greenhouse Office Technical Efficiency Guidelines in design and operational management.	Sections 6 and 8
6	Actions for the monitoring, regular auditing and annual reporting of "greenhouse gas" emissions and emission reduction strategies.	Section 10
7	A target set by the Proponent for the progressive reduction of total net "greenhouse gas" emissions and/ or "greenhouse gas": emissions per unit of product and as a percentage of total emissions over time, and annual reporting of progress made in achieving this target. Consideration should be given to the use of renewable energy sources such as solar, wind or hydro power.	Sections 10 and 11 Section 6.2.2
8	A program to achieve reduction in "greenhouse gas" emissions, consistent with the target referred to in (7) above;	Section 11
9	Entry, whether on a project-specific basis, company-wide arrangement or within an industrial grouping, as appropriate, into the Commonwealth government's "Greenhouse Challenge" voluntary cooperative agreement program.	Section 10.3.3
10	Review of practices and available technology	Section 6
11	"Continuous improvement approach" so that advance in technology and potential operational improvements of plant performance are adopted.	Sections 11 and 12

3 Project Description

3.1 Background

The Pluto gas field was discovered in April 2005 on the North West Shelf, approximately 190 km north-west of Dampier, Western Australia (**Figure 3-1**). Field evaluation suggests that Pluto gas field has a dry gas contingent resource estimate of approximately 4.4 trillion cubic feet (tcf) with recoverable condensate (42 MMbbl) and limited carbon dioxide (CO_2). The nearby Xena gas field was discovered in late 2006 and has a dry gas contingent resource estimate of approximately 0.6 tcf.

Woodside holds production licence WA-34-L (excised from exploration permit WA-350-L), which covers the Pluto and Xena gas fields. The Pluto and Xena gas fields are being developed through an offshore sub-sea gathering system which will be tied-back to the Pluto Riser Platform located in 80–85 m water depth. Gas will then be exported to shore via a 36 inch (diameter), 180 km trunkline for further processing. The Burrup Industrial Estate on the Pilbara coast is the selected location for the onshore processing and storage facilities, export facilities and associated infrastructure. The approved Pluto LNG Project has proceeded with the initial development on Train 1 and associated infrastructure to produce a design capacity of up to 4.8 million tonnes of Liquefied Natural Gas (LNG) a year. It should be noted that plant availability will not in practice be 100% and as such, actual production (and therefore resulting emissions) will be lower than this. Production for Train 1 is forecast to be 4.3 mtpa.

The present greenhouse gas footprint for the Pluto LNG Project comprises both reservoir CO_2 (~2 mol% or approximately 15% of total emissions) and equipment emissions (of which the main sources are gas turbines for gas liquefaction and power generation). Abatement opportunities have been assessed and adopted in design where economic, based on current Woodside economic assessment parameters. However further opportunities may exist both in areas of energy efficiency and optimisation of the LNG process during operation.

Woodside is committed to the global effort to limit greenhouse gas emissions and is making significant investment to reduce the overall footprint of the Pluto LNG Project. A key consideration in this respect is that the project will supply customers with an energy source that generates less greenhouse gas emissions than most other fossil fuels (e.g. coal). **Table 3-1** demonstrates the differences in greenhouse emission factors between LNG, diesel and coal as a fuel source for electricity generation. Woodside considers the supply of LNG as a key step in moving society to a lower carbon footprint. This approach also aligns with State and Federal Government policy and strategies.

Table 3-1 Greenhouse emissions factors for various fuel types used for electricity generation

Fuel Type	Emission Factor (kg CO_{2-e}/ GJ)		
	Carbon Dioxide	**Methane**	**Nitrous Dioxide**
LNG/ Natural Gas	51.2	0.1	0.03
Diesel Oil	69.2	0.1	0.2
Black Coal	88.2	0.03	0.2
Brown Coal	92.7	0.01	0.4

Source: DCCEE (2010)

3.2 Description of LNG Production

LNG will be produced through the cooling of natural gas below its condensing temperature of -162ºC. In a liquid state, the gas volume is one six hundredth of its volume in gaseous form and therefore can be stored and transported efficiently in tanks and carriers. The production of LNG and condensate involves a number of process steps that occur at different sites (see **Figure 3-2**). A description of onshore facilities associated with the approved Pluto LNG Project pertaining to Ministerial Statement No. 757 is provided in the following sections.

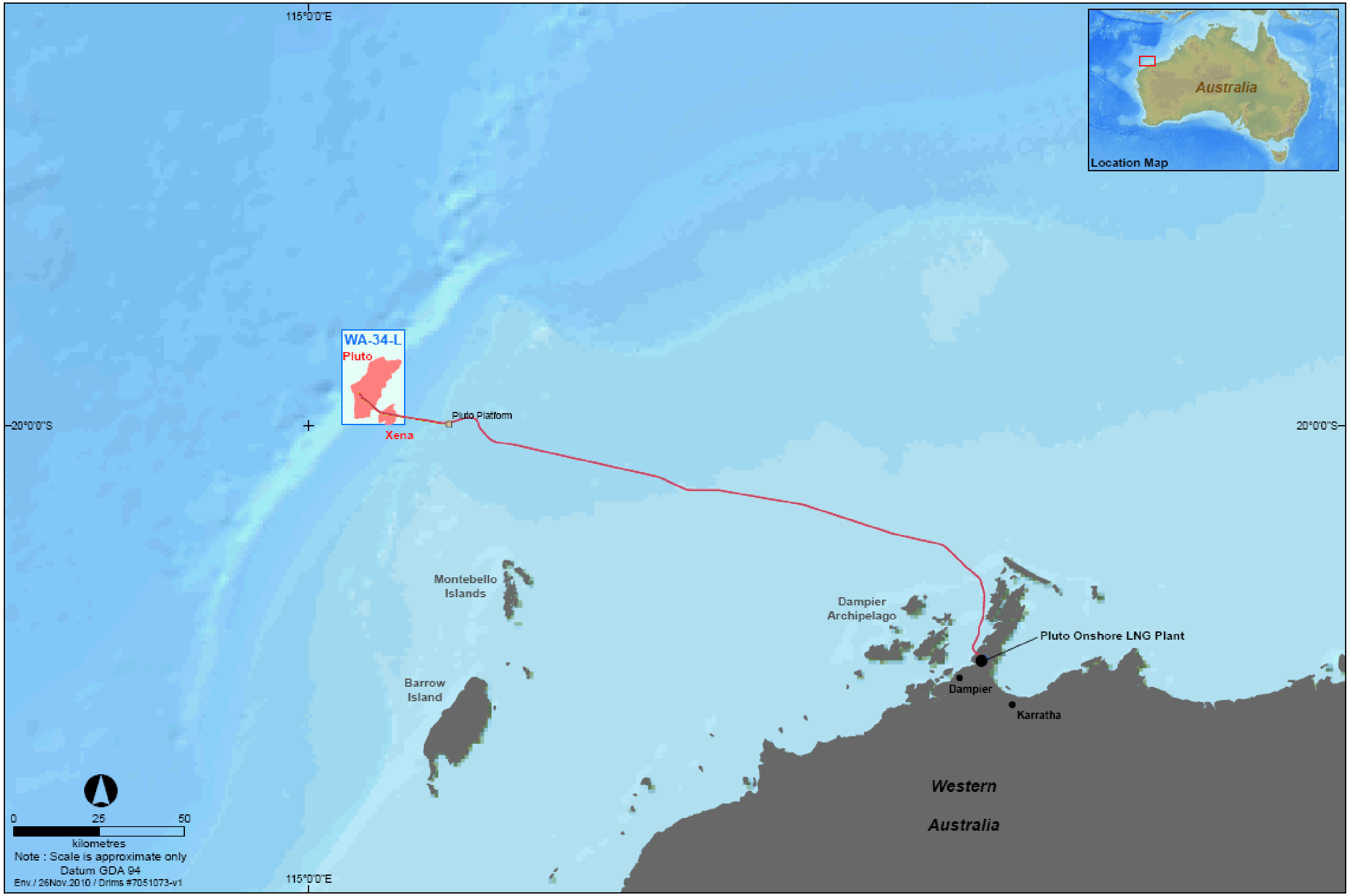


Figure 3-1: Location of the approved Pluto LNG Project

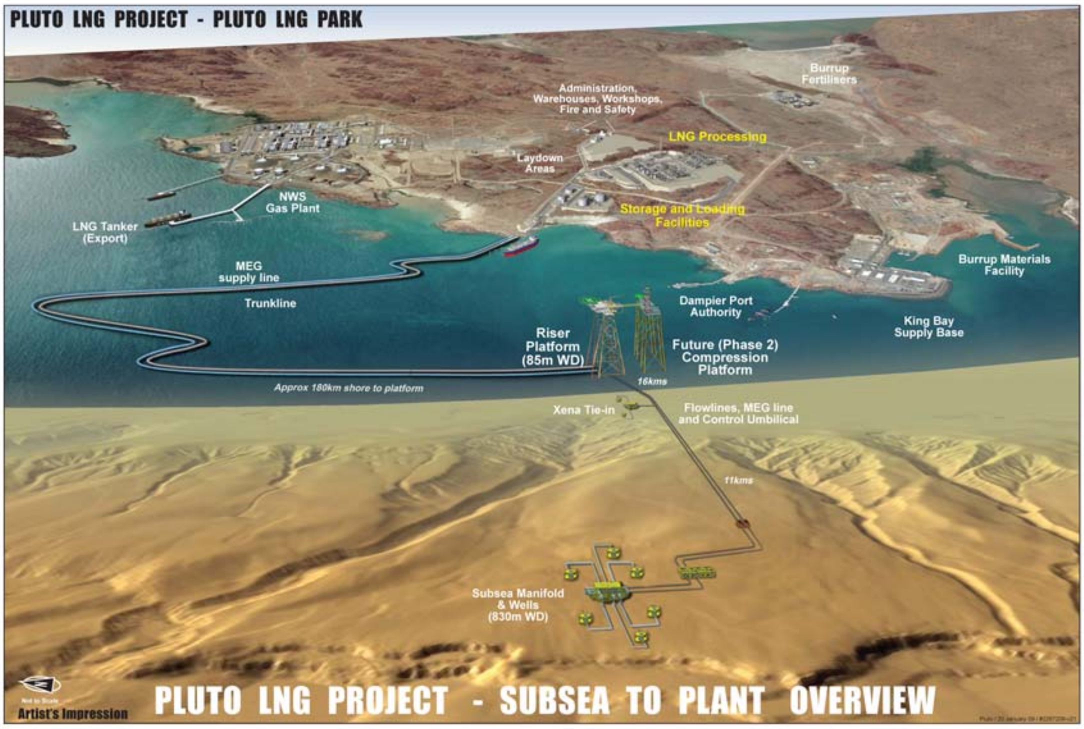


Figure 3-2: Approved Pluto LNG Project Conceptual Layout

3.2.1 Onshore Operations

3.2.1.1 LNG Processing Train

The onshore plant includes the following process phases as presented in **Figure 3-3**:

Gas receiver and inlet separation: fluids from the trunkline arrive at an onshore slugcatcher which separates condensate from water and gas and acts as a buffer between the trunkline and the downstream processing plant. The slugcatcher ensures that a stable gas flow is provided to the Acid Gas Removal Unit (AGRU).

The condensate stream is routed to the condensate stabilisation unit where the liquids are stabilised and cooled. The condensate is then combined with fractionation bottoms and routed to the condensate storage and export facilities.

The water stream is routed to the Monoethylene Glycol (MEG) regeneration unit where produced water is removed from the MEG.

Acid gas removal: feed gas from the slugcatcher is routed to the AGRU / amine treatment unit where CO_2 and sulphur components present in the gas are removed. The CO_2 is removed by active absorption (counter current circulation of feed gas with activated methyl-di-ethanol amine (aMDEA) solution) to prevent 'freezing out' (blockage) within the downstream cryogenic equipment.

Some low levels of hydrocarbons including benzene, toluene, ethylbenzene and xylene (BTEX) are co-absorbed during the acid gas removal stage. Specification of aMDEA in the acid gas removal system, as opposed to the traditional acid gas removal solvents, reduces the co-absorption of hydrocarbons by approximately 90%. This has a significant greenhouse saving, as well as occupational health benefits, and represents a key technological development incorporated into the Pluto LNG Plant design.

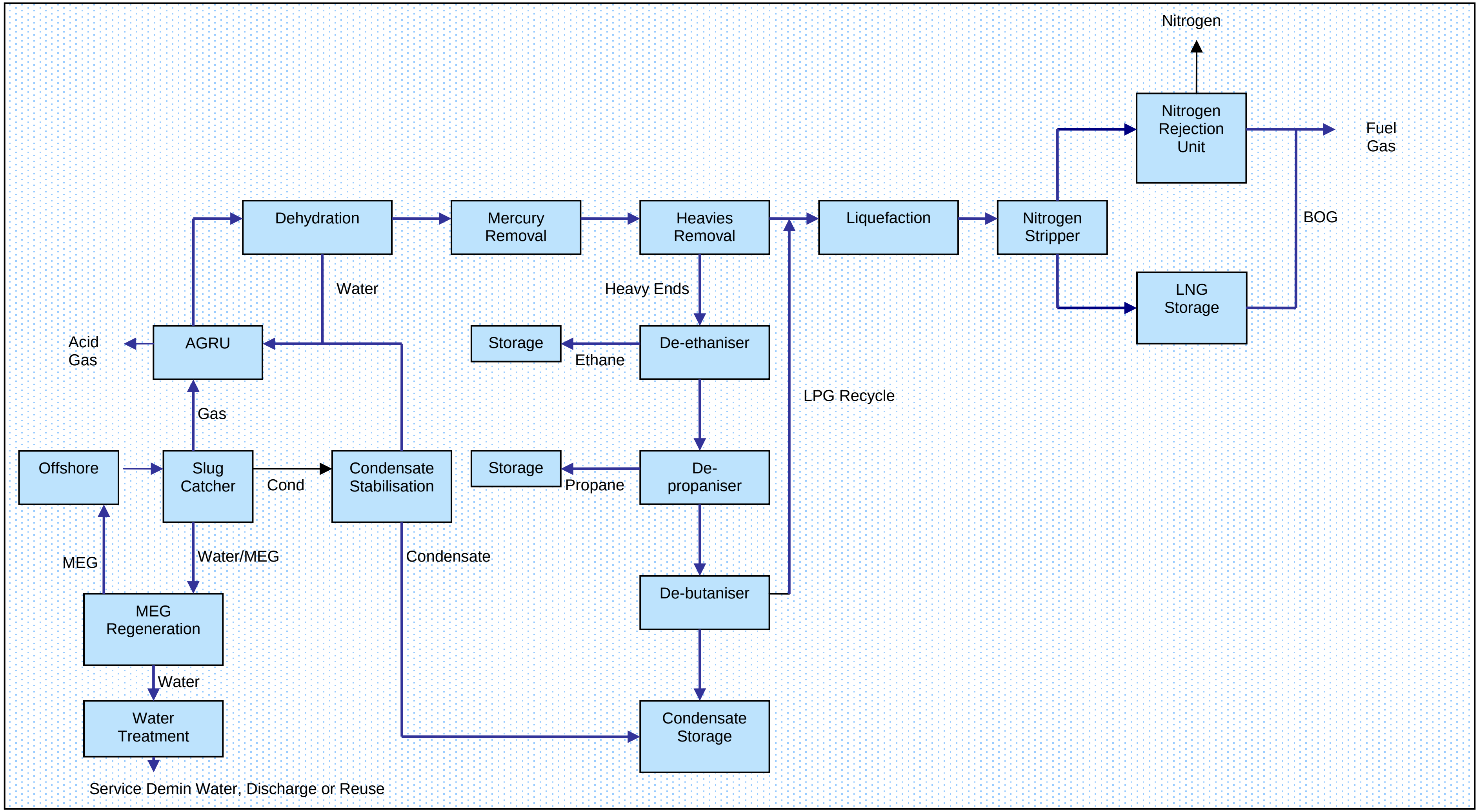


Figure 3-3 LNG Process Flow Diagram

The overhead gas from the regenerator column of the AGRU consists mainly of CO_2 and water. Some mercaptans, BTEX and other hydrocarbons may also be present. The concentrations of these in the overhead gas will be further reduced by approximately 98% by oxidation in a regenerative thermal oxidiser. The thermal oxidiser is a relatively recent technological advance, which offers significant improvement over traditional incinerator systems that use significant quantities of fuel gas to ensure combustion of BTEX and hydrocarbons in such a highly incombustible stream.

Gas dehydration: treated gas from the AGRU is routed to a dehydration unit, which dehydrates the feed gas stream to prevent water freezing out in the cryogenic equipment. The gas is chilled to a temperature slightly above the hydrate point in order to remove as much water as possible. The chilled gas is then dried in a molecular sieve system to remove the final traces of water and to prevent any downstream formation of ice.

Mercury removal: possible trace quantities of mercury are removed from the gas stream to prevent corrosion of the heat exchanger tubes. A mercury removal unit comprises a single bed of sulphur impregnated activated carbon. As soon as the gas passes over the bed, the sulphur reacts with any mercury in the gas and the mercury becomes embedded into the carbon granules.

Fractionation/ heavies removal: before the gas can be liquefied, heavier hydrocarbons which would otherwise freeze out in LNG need to be removed. For this process, the liquefaction unit receives heavier hydrocarbons from the scrub column bottoms and treats them to produce refrigerant for make-up, a Liquefied Petroleum Gas (LPG) stream for re-injection into the main process and a C5+ (‘pentane plus’) stream which forms part of the condensate product.

Liquefaction: This process is the main component of the LNG train and essentially chills the natural gas to a temperature at which LNG is produced. The refrigeration process is powered using large gas turbines and a series of cryogenic heat exchangers.

The liquefaction process includes a scrub column to remove heavier hydrocarbons to ensure that the product LNG complies with specifications and prevents freezing in the main cryogenic heat exchanger. The heavier hydrocarbon stream is sent to the fractionation system for further treatment, and the liquefied gas stream leaving the liquefaction system passes to the end flash system for further treatment.

The liquefaction process selected for the Pluto LNG Project utilises the Shell / Foster Wheeler C3MR System shown in **Figure 3-4**.

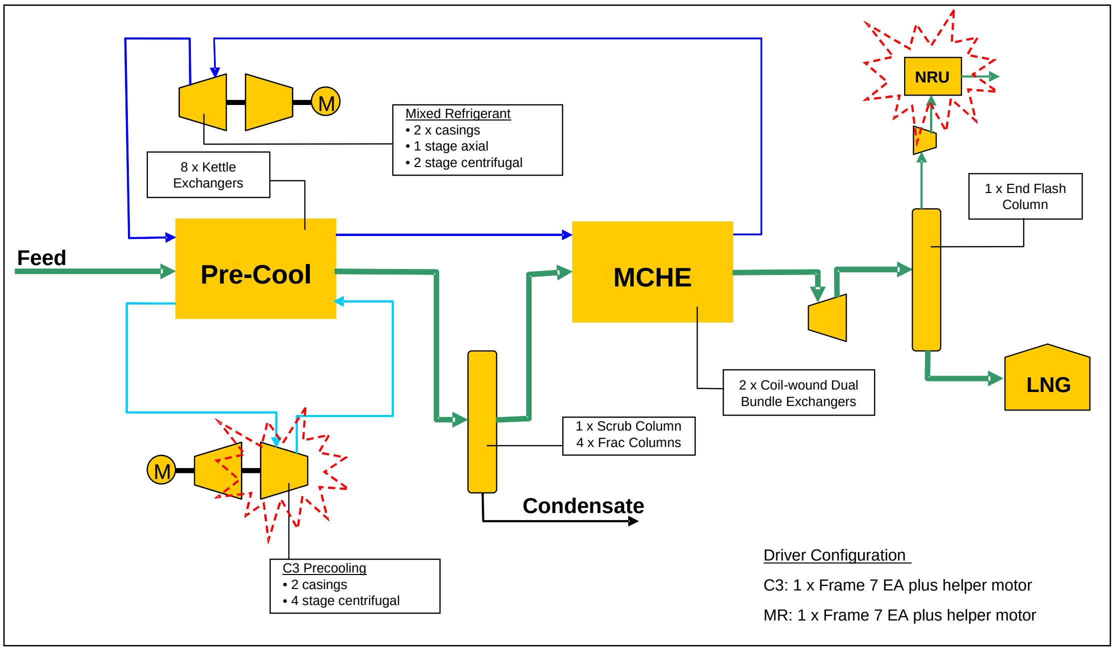


Figure 3-4: Shell/ Foster Wheeler C3MR Split Propane System

End Flash Nitrogen Removal: The end flash system ensures that the product LNG stream leaving the storage and loading facilities meets the product specifications for maximum nitrogen content. The end flash overhead stream passes through a nitrogen removal unit which produces a fuel gas stream, a nitrogen utilities stream and a reject nitrogen stream. The reject nitrogen stream will be vented to atmosphere and the LNG will be piped to the storage and export facilities.

3.2.1.2 Storage and Export Facilities

LNG storage and export facilities comprise:

- two LNG tanks, each with a storage volume of up to 120 000 m^3
- three condensate storage tanks (two main tanks and one small buffer tank) with double-emission seals, with a total capacity of approximately 130 000 m^3
- LNG export jetty with mooring and loading facilities
- designated area for laydown and future storage
- power substation for local distribution of power from main power generator
- field auxiliary room
- gatehouse and parking
- an LNG jetty security house and boom gate
- a jetty access road
- a pipe rack corridor for incoming and outgoing pipelines and services
- a flare system
- a boil off gas (BOG) reuse system (consisting of compressor, motor and power supply fuelled by fuel gas),
- drainage and effluent disposal facilities.

Refrigerant storage: propane and ethane are stored in liquid form to ensure sufficient make-up for the refrigeration loops is always available. Storage is in single spherical tanks. The refrigerants are extracted directly from the feed gas.

Condensate stabilisation, storage and export: the condensate feed from the slugcatcher is routed to the condensate stabiliser, where light ends are flashed off by heating. Gas from this process is compressed and returned to the liquefaction process. The condensate is cooled and routed to storage.

Monoethylene Glycol (MEG) regeneration facilities: The MEG that has been transported in the trunkline from the offshore platform to the onshore gas processing plant contains water and salts, both of which are removed to regenerate the MEG. The recovery process involves a series of steps including pre-treatment, storage, MEG re-concentration and finally MEG reclamation (desalting). The regenerated MEG is returned offshore and the produced water is directed to the wastewater treatment plant for treatment and disposal.

3.2.1.3 Ancillary Systems and Facilities

Fuel gas system: the onshore facilities run primarily with fuel gas. The required fuel gas pressure levels are designed to accommodate all gas turbine users. Feed gas is used as a secondary source of fuel gas and boil-off gas may also be used as fuel gas.

Main power generation: the main power generation system is located at the gas processing plant and includes the following key components:

- 4 x General Electric Frame 6 industrial open cycle gas turbines with capacities up to 35 MW each (higher for units equipped with waste heat recovery)
- compressors and generators
- inlet air system with self cleaning filters and silencing systems
- exhaust system including ductwork, silencer and stacks
- turbine lube oil system

- auxiliary cooling system
- dry low NO_x emission combustion system.

Waste heat recovery units: waste heat recovery units are provided to recover heat from gas turbines used for liquefaction and power generation to provide process heat to various components of the gas processing plant, including AGRU, MEG regeneration, feed heaters, fractionation, condensate stabilisers and high pressure fuel gas. This improves the overall plant efficiency. Waste heat recovery units are provided to deliver all main heat loads for the plant, with redundancy for when turbines equipped with waste heat are taken out of service for maintenance.

Boil-off gas system: During normal operation, natural gas is present within various pipelines including the rundown pipeline, the LNG storage tanks and in the offloading pipeline. The produced gas is handled by the boil off gas system. The configuration of the boil off gas recovery system will consist of a header leading to two parallel centrifugal boil off gas compressors of identical capacities. Normal operation (holding mode) utilises a single compressor, whilst the additional boil off gas compressor is utilised for ship loading mode. Ship loading for Train 1 occurs approximately every five days, meaning that the boil off gas re-compression system usually has 100% redundancy in case of compressor failure.

During tanker loading operations the quantity of boil off gas produced increases significantly and is generated from:

- displacement of gas in the empty LNG tanks with liquid LNG
- vaporisation of some of the newly loaded LNG as it enters ‘warm’ tanks
- export pumps and heat gain through the LNG loading lines; and
- the pressure differential between the LNG tanks and the LNG tanker vessel tanks.

Boil off gas is directed back to the processing facilities. There are only two principal cases where gas is to be flared from loading activities with this system – 1) in the event that one of the boil off gas compressors fails during loading; and 2) in the final stages of de-inerting an inerted LNG tanker (e.g. after tanker maintenance) as natural gas mixes with inert gas purging from the ships hold. There are no practical methods currently available for recovering the small quantity of gas purged during ship de-inerting.

Flare and relief systems: flaring has been minimised within the context of the carbon-copy NWSV Train V approach taken for the Pluto LNG Project. Flaring has been, and will be, minimised by a combination of optimising the process design (e.g. by selectively increasing equipment pressure ratings and adding recycle pumps and equipment), deliberate management during operation and effective maintenance of relief valves and pressure control valves. The onshore facilities have three flare systems (and a spare), as follows:

- <u>Storage and loading flare system:</u> designed to safely collect and dispose of all releases due to depressurising, relief, maintenance and commissioning activities for the storage and loading facilities. The flaring regime includes a continuous small pilot light and occasional flaring in the event that the BOG compressor(s) fail during loading or during the rare occasions when an inerted LNG ship arrives for loading. As 100% redundancy is provided in the boil off gas compressor system during holding (non-loading) mode to account for equipment failure and maintenance, flaring would not be anticipated outside of ship loading periods.

- <u>Pressure relief and liquid disposal flare system</u>: designed to safely collect and dispose of hydrocarbons containing streams that are released during start-up, shutdown, plant upsets and emergency conditions. Flaring occurs continuously for up to approximately six months during the commissioning period as the system will at times be too warm to produce LNG. During plant operation, flaring will be intermittent and will occur during maintenance, shutdown and upset conditions. The system includes:
    - *Warm wet flare*: designed for wet vapour and warm blowdown and will include a knock-out drum to separate any liquids from the gas prior to it being routed to

warm wet flare stack which currently has a permanently lit pilot light system and an ignition monitoring system.

- *Cold dry flare*: designed for dry vapour and cold blowdown and will also include a knock-out drum and other systems as per the warm wet flare.
- *Common spare flare:* designed so that it is interchangeable between the cold dry and warm wet flare systems whilst the plant is operational.

Freshwater cooling system: The main cooling system for the gas processing plant is provided by air-cooled finned heat exchangers. In addition, a relatively small amount of cooling is provided by a fresh water system supplying cooling water for motors and lube/seal oil skids within the LNG train. The refrigeration and end flash gas compressors will be the major consumers of cooling water.

Fire protection system: Fire water systems are provided for the gas processing plant and the storage and export facilities. The fire water system at the gas processing plant includes a water storage tank and pumps, each rated for 100% of the total firewater requirements.

LNG carrier emissions: LNG carriers transport product to overseas clients, comprising both carriers operated by Woodside and supplied by LNG customers. Typically, hydrocarbon combustion within the propulsion systems of LNG carriers will result in greenhouse gas emissions.

Emissions from carriers provided by the customer are outside of the operational control of Woodside.

The carrier(s) operated by Woodside have dual fuel diesel/electric propulsion systems, which are in the order of twice as efficient as the existing carrier fleets used by other operators utilising steam turbines for propulsion. Ultimate responsibility for the greenhouse gas emissions from these carriers will be determined by the nature of the individual supply contracts (i.e. Free on Board or 'at terminal' basis) and the voyage destinations. Subsequent to the majority of the supply contracts being established, Woodside's component of the LNG carrier greenhouse gas emissions will be estimated and evaluated as per Australian and international greenhouse reporting protocols.

4 Policy and Strategies

4.1 Overview

Woodside is committed to minimising greenhouse gas emissions from its production of energy products whilst remaining globally competitive. Woodside operates in accordance with a Greenhouse Strategy and a Greenhouse Policy (refer to Section 4.3) recognising that global greenhouse emissions and its effect on climate has become of concern to government, regulators, industry and the community.

Woodside's core business is in the production of energy products such as LNG and condenstate. In doing so, the Company recognises that greenhouse emissions are generated as a result of these activities. However the opportunity to replace fuels with a greater greenhouse footprint is significant and must be realised to secure a low carbon future.

This section briefly describes Woodside's commitment to minimising greenhouse gas emissions in the context of providing an energy source for the future.

4.2 LNG – Energy Source for the Future

Energy is an essential commodity and can be derived from many sources. Woodside strongly believes that natural gas is the energy for the future to displace traditional fuel sources, such as coal, that are well known to have a greater greenhouse footprint (**Table 4-1**). Western Australia is fortunate to have, as at August 2008, 2694 MW of installed natural gas generation plant versus 2194 MW of coal generation plant to provide essential electricity to meet the demands of the metropolitan region connected to the South West Interconnected System (SWIS) (Office of Energy, 2008). Only a small proportion of the SWIS relies on alternate fuel types such as distillate (83 MW) and renewables (215 MW) (Office of Energy, 2008).

Comparative analysis shows eastern counter-parts of NSW and QLD are not so fortunate, with government continuing to encourage the development of coal resources. Over 80 new coal projects are proposed for NSW and QLD (Lampard et al, 2010).

Developed countries such as Australia, have the opportunity to support developing countries, in the transition from traditional fuels sources to cleaner fuels such as LNG. The export of LNG is necessary to support the needs of developing countries. For example, Australian exports of LNG to China can be used in place of more emissions intensive energy sources such as coal and fuel oil. For every tonne of CO_2 emitted in LNG production within Australia, at least four tonnes can be reduced globally by displacing coal fired power generation.

Source: Worley Parsons 2010

Table 4-1 Comparison of Emission Intensity of Various Fuel Types for Electricity Generation (tonnes CO_{2-e}/ MWh)

4.3 Woodside's Greenhouse Policy

greenhouse policy

objectives

Woodside is committed to minimising greenhouse gas emissions from the company's production of energy products while remaining globally competitive. We seek to achieve this through a portfolio of actions, including improvements in technology and efficiency, and market measures.

The company seeks to increase its contribution towards lowering global emissions through the use of natural gas, where it replaces fuels with a higher greenhouse footprint. Woodside believes that the global benefits of natural gas are part of the transition to a lower carbon future.

strategy

Woodside achieves these objectives by:

- Promoting natural gas as the energy source that helps the global transition to a lower greenhouse footprint
- Setting internal targets which drive us towards ongoing reduction in our carbon footprint
- Driving energy efficiency and improving resource use in our design and operating practices
- Pursuing greenhouse gas emissions reduction technologies that support our core business
- Minimising the possible adverse effects of climate change on the assets we design and operate
- Evaluating opportunities in carbon markets where they add value to our business, mitigate a specific future risk and provide a source of competitive advantage for Woodside
- Advocating the development of legislation which results in comprehensive accreditation of emissions reductions and improved environmental outcomes, including recognition of prior actions or investments

application

The Managing Director of Woodside is accountable to the Board of Directors for ensuring this policy is effectively implemented through annual performance reviews. This policy will be reviewed regularly and updated as required.

Responsibility for the application of this policy rests with all Woodside employees, contractors and joint venturers engaged in activities under Woodside operational control. Woodside managers are also responsible for promotion of this policy in non-operated joint ventures.

December 2010

woodside

4.4 Woodside's Approach to Greenhouse Gas Abatement

It is a priority for Woodside to reduce greenhouse gas emissions at source, either through efficiency improvements or sequestration technology solutions. Significant focus is provided at the design phase of projects to mitigate emissions. The following sections of this document demonstrate the success that the Pluto LNG Project has obtained in improving greenhouse efficiency for this development.

As an example of Woodside's commitment to implementing its greenhouse gas Strategy and Policy the following marquee greenhouse gas reduction initiatives and projects, in reverse chronological order, have been conducted (Woodside 2006; 2009):

- **Karratha Gas Plant - Thermal Combustion Unit Decommissioning**: With the replacement of sulfinol as the acid gas solvent in 2005, co-absorbed hydrocarbon concentrations in the stripped acid gas (CO_2) stream were significantly reduced. This allowed the thermal combustion unit, effectively a high temperature incinerator that combusted these entrained hydrocarbons, to be decommissioned safely. This resulted in a reduction of 55,000 tonnes $CO_{2\text{-}e}$ per annum and also resulted in the saving of 19,000 tonnes per annum of gas.
- **Karratha Gas Plant - Solvent change project:** The replacement of solvent used for removing CO_2 from natural gas at the Karratha Gas Plant (Trains 1 – 4) has enabled a reduction of 350,000 tonnes $CO_{2\text{-}e}$ per annum (equivalent to 7 million tonnes of $CO_{2\text{-}e}$ over the projected life the project). As well as reducing greenhouse emissions, the solvent replacement project also results in greater production efficiency, that is, less emissions and increased production. This project gained significant recognition from the former Australian Greenhouse Office with Woodside receiving Greenhouse Challenge Plus Large Business Award for Outstanding Achievement in Greenhouse Gas Abatement in 2005.
- **Karratha Gas Plant - Flash gas project:** This project set out to determine mechanisms to reuse waste gas from the LNG process. This was successfully implemented with the reuse of waste gas as fuel for the process enabling a reduction of 570,000 tonnes of $CO_{2\text{-}e}$ per annum. This project also gained significant recognition with Woodside receiving an award from the former Australian Greenhouse Office in 2001.
- **Karratha Gas Plant - Enhanced adsorption in Sulfinol absorber column:** Structured packing (honeycomb metallic structure) was introduced to replace conventional trays in the Sulfinol absorber columns of LNG Trains 1 and 2. Sulfinol spreads over this material as a thin film. The structured packing material facilitated a change in Sulfinol composition which resulted in significantly reducing the amount of co-absorbed methane. This has resulted in a reduction of $CO_{2\text{-}e}$ by 20%. The proven success of this project has allowed for this technology to be adopted for subsequent Woodside projects.
- **Offshore gas re-injection:** At the northern Endeavour and Legendre oil operations in Australia, Woodside has re-injected gas that cannot be economically sold. This enabled the abatement of 14 million tones of $CO_{2\text{-}e}$ over the life of these two projects.
- **Greenhouse Challenge**: Woodside has been a member of the Australian Government's Greenhouse Challenge Program since 1997 up until the Program's cessation in 1 July 2009. As part of this program Woodside purchased approximately 100,000 tonnes of Verified Emission Reduction Units (VERUs) in 2005. These were sourced mainly from landfill gas capture and avoidance projects. These units were retired in 2009 to partially offset Woodside's greenhouse gas emissions footprint.
- **Geosequestration Research and Development:** Woodside has previously supported the research and development being carried out by the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC). The CRC is one of the world's leading collaborative research organisations focused on carbon dioxide capture and geological sequestration (geosequestration, carbon dioxide capture and storage, carbon capture and storage, or CCS).
- **Energy Efficiency Opportunities Program:** Woodside has participated in the Energy Efficiency Program since 2007 and has successfully implemented several energy efficiency measures. In 2010, Woodside demonstrated an annual energy saving of 3,000,000 GJ, equivalent to powering 50,000 households.

These initiatives and projects have required Woodside to allocate funds to reduce greenhouse gas emissions. Woodside and its joint venture partners have committed some A$360 million[1] in

[1] Exact reported figure is A$364 million. Woodside equity share figure is A$204 million

capital and operational expenditure since 1997 to reduce projected business-as-usual emissions by up to 49 million tonnes of greenhouse gases[2].

Woodside acknowledges that as its business grows, the overall greenhouse gas emissions profile will also grow and further action to reduce emissions intensity may be implemented.

[2] From 2007 Greenhouse Challenge Report

5 Benchmarking

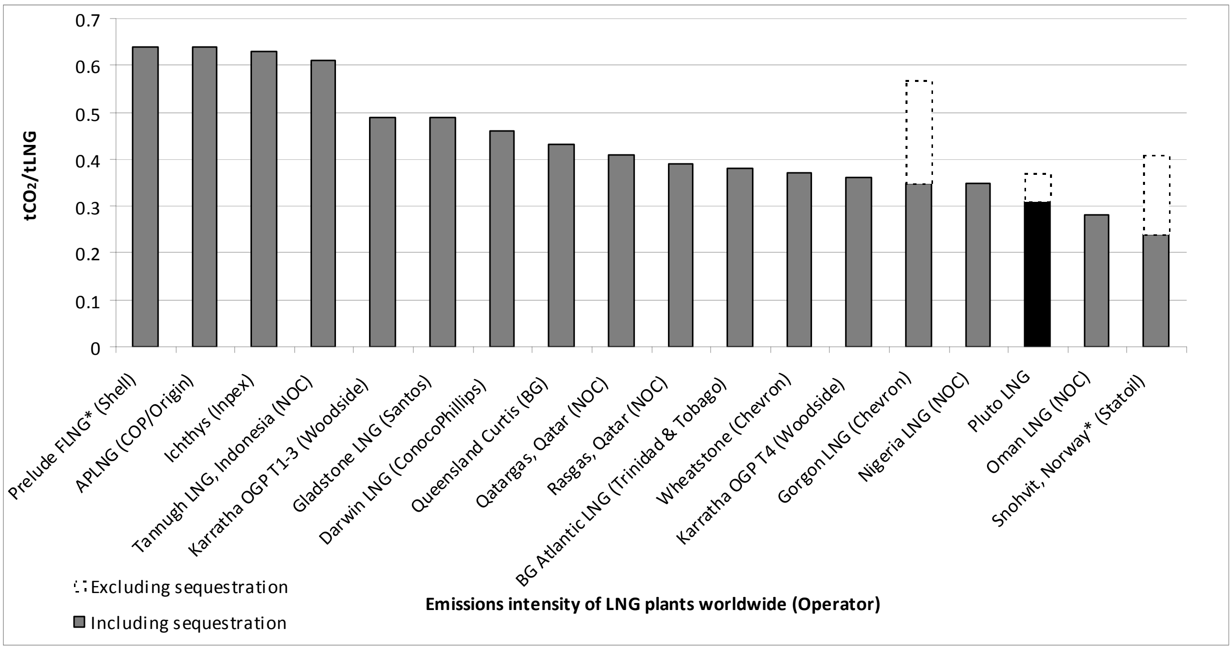
Benchmarking allows for a comparative analysis to identify previous and current status of a certain element in an industry, in this case Woodside present benchmarking data with respect to greenhouse intensities for LNG production. Comparable benchmarking of a gas processing plant is difficult to undertake due to the propriety nature of data relating to plant performance and the difference in greenhouse efficiency that occur due to local and site specific factors. Greenhouse gas emissions intensity can be influenced by a range of internal (technology) and external (environmental / policy) factors (Woodside, 2007; Chevron, 2010):

- the proportion of CO_2, N_2 and other inert gases that naturally occur in the reservoir gases used to supply the LNG plant. Inerts contained in the feed gas stream (from the reservoir) must largely be removed prior to, or during, the liquefaction process. CO_2 and other inerts removed are usually vented to atmosphere. Venting of CO_2 directly influences the greenhouse footprint of an LNG plant and the removal process also requires energy, thus impacting the energy efficiency of the process and thus the greenhouse footprint. This can only be reduced through sequestration, however the process of sequestration itself has an impact on energy efficiency.
- the ambient temperature of the surrounding environment at the location of the LNG plant (lower temperatures enhance air cooling of LNG and turbine efficiency). The cooling efficiency of the refrigeration loop is improved when cooling takes place in areas of lower ambient temperatures as compared to warmer temperatures. Ambient temperatures also influence the efficiency of gas turbine operation (compressor efficiency is favoured by cooler temperatures). Therefore cooler temperatures result in greater efficiency and less greenhouse emissions for the same power output compared to a gas turbine operating in a warmer climate.
- the technology, process and policy factors that influence greenhouse intensity include choice of liquefaction technology, power generation – choice of turbines and configuration, waste heat recovery, the use of air or water for processing cooling, acid gas removal process and market-based offsets.
- the level of integration with other gas processing facilities such as domestic supply, LPG extraction and condensate production. A larger site typically has a smoother electrical demand and allow greater flexibility for power generation plant. Integration with other facilities including domestic gas supply, LPG extraction and condensate production, also provides greater opportunity for waste heat utilisation thereby increasing overall energy efficiency of the facility.
- the capacity for local electricity generation infrastructure to supply electrical power. This enables generation plant to be operated more efficiently as the grid can be used for sparing capacity and larger scale power generation has greater capacity for efficiency for the same price per megawatt output. In a reporting sense, greenhouse emissions from the consumption of grid power is included and are reportable as Scope 2 emissions, however the greenhouse emissions from the production of electricity for the grid is accounted for by the supplier (refer to National Greenhouse and Energy Reporting Guidelines).

In the benchmarking data provided in this section (see **Figure 5-1** and **Table 5-1**), these elements are shown to affect the performance of several existing LNG plants. The data that has been collated for comparative purposes has been sourced from publicly available documents, mainly environmental impact assessment reports. Although every effort has been made to provide a comprehensive and accurate comparison of LNG plants located within Australia and internationally, it does not include all LNG plants worldwide, some of which are less efficient (tCO_{2-e}/t LNG) than the least efficient plant listed here (Prelude FLNG and Ichthys LNG Projects). The greenhouse emission intensities shown in **Figure 5-1** are based upon greenhouse emissions and the published LNG (or total product) production capacity of the plant.

The Pluto LNG Project's GHG intensity (for Train 1) is approximately 0.37 tCO_{2-e} /t LNG, further lowered to 0.31 tCO_{2-e} /t LNG when market abatement of reservoir CO_2 is considered. The detailed emissions profile for Train 1 is provided in **Section 7**. The benchmarking illustrates that the performance of the Pluto LNG Project is representative of the LNG industry's current average greenhouse efficiency. In addition to the considerable efforts of Woodside in identifying and implementing greenhouse gas mitigation opportunities during the design phase, reservoir CO_2 has been offset to further lower greenhouse gas emissions to 0.31 tCO_{2-e} /t LNG, which places it as one of the most greenhouse friendly LNG projects worldwide. The initiatives that have been taken during the design process are discussed in further detail **Section 6**. From **Table 5-1** it can be seen that very few current and proposed LNG plants within Australia and internationally have committed to carbon sequestration (either carbon capture and storage, or bio-sequestration).

Figure 5-1 Greenhouse Intensity of Major LNG Plants Worldwide (Existing and Planned)



Source: ConocoPhillips (2002); Woodside (2006); Yost and DiNapoli (2003); Chevron Australia (2008, 2010); Inpex Browse (2010); Shell Development Pty Ltd (2009); QGC Ltd (2009), Tannugh (2005) and WorleyParsons (2010), Statoil (2009).

The key environmental and technological factors contributing to the efficiency differences (shown above) are provided within **Table 5-1**. Overall greenhouse footprints of the sites are strongly associated with reservoir CO_2 content and ambient temperatures. The Snohvit facility, which has the lowest greenhouse emission intensity, is based in the Arctic Circle with an average ambient temperature of approximately 0°C. The cooler ambient conditions and connection to the local energy grid provide a significant efficiency advantage compared to the other sites.

Train 4 at the Karratha Gas Plant (KGP) is in the order of 0.03 tCO_{2-e} /t LNG more efficient than Phase 1 of the Pluto LNG Project. KGP feed gas has a higher CO_2 content from the North West Shelf gas fields. Notwithstanding this, KGP facility is of a larger scale, enabling more flexibility with respect to power generation and sparing and waste heat recovery. Comparably, older LNG Trains 1-3 at KGP have a current greenhouse intensity of approximately 0.49 tCO_{2-e} /t LNG, demonstrating the significant improvements made in design and adopted by Woodside over the course of the last two decades. Initial KGP Train 1 greenhouse emissions were higher, at approximately 0.6 tCO_{2-e} /t LNG, prior to efficiency improvements, improvements due to scale and technology improvements instigated by Woodside and the North West Shelf joint venture partners.

According to the available information for the facilities benchmarked, Oman LNG is the most technically greenhouse efficient facility in current operation. Oman LNG is more efficient than the Pluto LNG Project by 0.09 tCO_{2-e} /t LNG, based on emissions from the plant. It is estimated that approximately 43% of this difference is attributable to lower reservoir CO_2 content at Oman. Other factors such as using once through seawater for cooling purposes contribute to the remainder 57% of this efficiency difference.

The proposed Prelude Floating LNG Project and Ichthys LNG Project indicate the highest greenhouse emissions intensities of 0.64 and 0.62 tCO_{2-e} /t LNG, respectively (Shell Development Australia Pty Ltd, 2009; Inpex Browse Ltd, 2010). Combinations of technology and high CO_2 reservoir content contribute to the relatively high greenhouse emissions for these two projects. Neither of these projects have committed to carbon sequestration, although Inpex Browse states that it is investigating geo-sequestration.

Table 5-1 Comparison of Project Elements Affecting Greenhouse Gas Efficiency of Major LNG Plants within Australia and Internationally (Existing and Planned)

Project	Capacity (MTPA)	Commission Date	Aero-Derivative Turbines		Waste Heat Recovery		Combined-cycle Gas Turbines		aMDEA Solvent*	Carbon Sequest.	Reservoir CO_2 mol%	Other Factors	
			Process	Power	Process	Power	Process	Power				Advantages	Disadvantages
Australia													
KGP T1 – T3	7.5-8	1984 - 2004	N	N	N	N	N	N	Y	N	2.5		warm climate
KGP T4	4.5	2004	N	Y	Y	N	N	N	Y	N	2.5		warm climate
Darwin LNG	3.7	2006	Y	N	Y	N	N	N	N	N	6.0		equatorial climate
KGP T5	4.5	2008	N	Y	Y	N	N	N	Y	N	2.5		warm climate
Pluto LNG	4.8	2011	N	N	Y	N	N	N	Y	Bio	2.0	low reservoir CO_2	warm climate moderate N_2 content
Gorgon LNG	15	2013	N	N	Y	N	N	N	Y	Geo	14 Gorgon 0.5 Jansz		sub-sea production system high reservoir CO_2
Gladstone CSG LNG	10	2014	ND	ND	ND	ND	ND	ND	ND	UC	N/A		warm climate
Curtin Island CSG LNG	12	2014	Y	N	Y	N	N	N	ND	N	<1% reservoir CO_2	low reservoir CO_2	
Prelude FLNG	3.6	2015	N	N	N	N	N	N	Y	N	9% vol	sub-sea production system, deep sea water for cooling Steam turbines run on LP boil-off gas	high reservoir CO_2
Ichthys LNG	8.4	2016	N	UC	Y	UC	N	UC	Y	Geo UC	8 Brewster 17 Plover		high reservoir CO_2
Wheatstone LNG	8.6	2016	Y	Y	Y	ND	N	N	Y	N	ND		warm climate
International													
Qatargas, Qatar T1 & T2	4.8	1993	N	N	N	N	N	N	N	ND	2.1	low reservoir CO_2	equatorial climate flaring integral to operations
RasGas, Qatar	6.4	1999	N	N	N	N	N	N	N	ND	2.3		equatorial climate flaring integral to operations
Nigeria LNG	6.1	2000	N	N	N	N	N	N	Y	ND	1.8	government regulations to reduce flaring low reservoir CO_2	
Oman LNG	6.9	2001	N	N	N	N	N	N	Y	ND	1.0	use of once-through seawater for cooling low reservoir CO_2	
Atlantic LNG	15.1	2005	N	N	Y	N	N	N	N	ND	0.8	low reservoir CO_2	
Snohvit, Norway	4.2	2007	N	Y	Y	Y	N	N	N	Geo	8.0	cool climate, electrical drive turbines for process	sub-sea production system. Medium to high reservoir CO_2

Source: Inpex Browse Ltd (2010), Woodside (2009), Chevron (2008, 2010), QGC Ltd (2009), Shell Development Australia Pty Ltd (2009),
Notes: CSG = Coal Seam Gas; ND = no data publicly available; UC = under consideration; bio = biosequestration; geo = geosequestration, * or similar amine-based variant.

6 Greenhouse Gas Mitigation – Design Achievements

6.1 Overview

The benchmarking of greenhouse performance of the Pluto LNG Project against other existing and planned projects within Australia and across the globe, clearly illustrates the ongoing efforts taken by Woodside to reduce greenhouse emissions to as low as reasonably practicable, against wider industry performance. This section describes the mitigation measures that have been adopted in the design and selection of technology for the Pluto LNG Project, against the benchmark of KGP Trains 1-3. These measures represent either:

- **No regret measures**: those which can be implemented and are effectively cost-neutral or generate value (Section 6.2);
- **Beyond no regret measures:** measures are those which can be implemented and involve additional costs which are not expected to be recovered (Section 6.3).

Woodside recognises that the opportunity for greenhouse gas mitigation at the design phase provides the largest opportunity to minimise emissions. As result, significant focus on greenhouse is always provided during the Basis of Design (BOD) phase as well as Front End Engineering Design (FEED) in accordance with the requirements of Woodside's Management System and Greenhouse Policy.

6.2 No Regret Mitigation Measures

Table 6-1 summarises the main "no regret" greenhouse reduction initiatives implemented for Train 1 of the Pluto LNG Project, including an estimate of the annual greenhouse reductions achieved. Further detail around each initiative is provided in the following sub-sections.

Table 6-1 Summary of Main "No Regret" Greenhouse Abatement Initiatives for the Pluto LNG Project

Abatement Opportunity	* GHG savings (tCO_{2-e}) p.a.	GHG savings (tCO_{2-e} / tLNG)	Comments / Assumptions
Improved Gas Turbine Efficiency (Power Generation)	336,000	0.08	Based on evaluation of GE Frame 6 turbines against base case of GE Frame 5 turbines, representing higher individual turbine costs but reduced turbine numbers and superior fuel efficiency economics.
aMDEA	384,000	0.09	Assessment assumes no difference between aMDEA and sulfinol system to install.
Flash Gas Recovery	129,000	0.03	Based on alternatively providing no flash gas recovery.
Regenerative Thermal Oxidiser	25,800	0.006	Based on provision of a regenerative thermal oxidizer over a traditional thermal combustion unit.
Waste Heat Recovery	86,000	0.02	Estimate based on alternative gas firing of process heat demands.
Optimising Nitrogen Content in fuel Gas	56,000^	0.01	N_2 available from Pluto reservoir gas and nitrogen rejection unit, allowing fuel gas leaning and efficiency improvement (fuel gas in vs power out).
Floating Roof Condensate Storage Tanks	ND	ND	Design selection principally based on reducing VOC emissions, however power (and thus fuel use) is lower compared with alternative solutions (i.e. fixed tanks with vapour recovery). Capital costs comparable between floating and fixed tanks with vapour recovery for larger tanks.

Abatement Opportunity	* GHG savings (tCO_{2-e}) p.a.	GHG savings (tCO_{2-e} / tLNG)	Comments / Assumptions
			Other drivers (footprint, volume etc) are important in technology selection.
Nitrogen Flare Purging	1,200	0.0003	Estimated based on 2006 flare gas study.
Main Cryogenic Heat Exchanger Redesign	0 – 73,000	0 – 0.017	Reduces risk of unplanned flaring events, however magnitude not able to be quantified, as any MCHE leakage is not "planned". Upper end estimate based on complete elimination of leakages.
Tandem Dry Gas Seals	0 - 39,460	0 - 0.009	Upper figures based on KGP Train 1-3 wet seal emissions, scaled to capacity of Pluto T1. Zero estimate based on KGP Train 4-5 comparable design.
Specification of High Efficiency Motors	ND	ND	Equipment specification considered best available technology not entailing excessive cost (BATNEEC)
Minimisation of relief valves to atmosphere	ND	ND	Insufficient data to estimate the greenhouse savings, as benchmarking is subjective.
Dual boil-off gas compressors	ND	ND	Greenhouse savings result from compressor downtime (either planned or unplanned) during holding mode.
Total Reduction in Business as Usual	**1,020,000 tCO_{2-e} p.a.**	**0.23 tCO_{2-e}/tLNG**	Potential MCHE reductions not included in total, due to range uncertainty. No reduction for tandem dry gas seals included, as Pluto design is in line with KGP Train 4-5.

*Based upon LNG production of 4.3 MTPA (w/avail)

#Annual emissions assumed constant for 20 years.

^ * Removal of nitrogen (and other inerts) imposes an efficiency penalty on the LNG process, as outlined in Chapter 5. The efficiency penalty associated with the requirement to remove nitrogen from the gas is able to be partially offset by nitrogen leaning of the turbine feed gas.

6.2.1 Technology Choice

During the early phases of design, two technology options were investigated for liquefaction at various production capacities. These included:

- Shell FosterWheeler Worley (SFWW) C3MR process (implemented at NWS Train 5)
- Bechtel-ConocoPhillips (BCOP) Cascade process (implemented at Darwin LNG)

Technologies not previously adopted in Australia (such as Black & Veatch) were discounted early in the process due to potential risk of exceeding Pluto's challenging implementation schedule.

A comparative analysis (**Table 6-2**) of key criteria including cost performance, production values which meet required high heating value (HHV) parameters (to comply with Woodside's customer requirements) and capital expenditure was undertaken during the early process of basis of design. The outcomes indicate that the SFWW was, at the time of selection, more favourable in all categories.

Further qualitative analysis was undertaken addressing evaluation criteria of safety, schedule certainty, commercial aspects, cost certainty, environmental aspects, technical and quality aspects, operations and maintenance, and project management aspects. The outcomes are shown in **Table 6-3**, indicating that the SFWW C3MR System is also favourable over the alternate options across these criteria.

Table 6-2 Comparison of Liquefaction Technology Options

Technology Provider	Technology Arrangement	CAPEX (ranked 1-4)*	Production (per train)	HHV	Schedule (ranked 1 – 4)
BCOP	Cascade 2-2-2	2	3.15 Mtpa	Non compliant in single train arrangement	Not scheduled
	Cascade 2-3-2	1	3.61 Mtpa	Compliant	2
SFWW	C3MR	4	4.73 Mtpa	Compliant	1
	C3MR Extended Liquefaction	3	5.49 Mtpa	Non-compliant	

Source: Woodside (2006)

Note: Ranking 1 is highest or longest; 4 is lowest or shortest. Ranking is shown rather than actual values due to commercial-in-confidence nature of information.

Table 6-3 Qualitative Analysis of Liquefaction Technology Options

Criteria	BCOP		SFWW	
	Cascade 2-2-2	Cascade 2-3-2	C3MR	C3MR Extended Liquefaction
Safety	2	2	1	1
Schedule Certainty	2	2	2	3
Technical & Quality	1	1	1	1
Operations & Maintenance	2	2	1	1
Project Management	2	2	2	2
Commercial & Customers	3	2	2	3
Cost Certainty	1	1	1	1
Environmental	1	1	2	2
Total Ranking	14	13	**12** **[most favourable]**	14
Total Weighted Ranking	**66**	**64**	**72**	**70**

Source: Woodside (2006)

Ranking indicates 1 = most favourable; 3 = least favourable.

Total ranking: lowest score indicates most favourable.

Weighted ranking provides greater importance to some of the criteria over others. Therefore, the highest score indicates most favourable.

On this basis, the emission estimates provided for greenhouse gases are based upon the implementation of the SFWW C3MR technology.

6.2.2 Selection of Preferred Power Generation Technology

Approximately 30% of annual greenhouse emissions from Train 1 will be derived from electrical power generation; therefore the selection of suitable technology has the ability to influence the greenhouse emission intensity for the project.

Train 1 requires a reliable power supply source to meet a requirement of approximately 108 MW (Woodside 2009b). The selection of appropriate power generation technology is undertaken based upon the following criteria:

- reliability – this is crucial to maximise operational availability of the LNG Plant and to minimise the frequency of maintenance, upset conditions and resultant flaring.
- proven technology – investment in proven technology provides confidence that the LNG Plant will be powered by technology that has been installed and operated successfully in other locations. Investment in unproven technology or techniques is not a business strategy that is adopted by Woodside. The preferred technology must also be equipped with low NO_x emission technology.

- stability – stable operations, hence stable power supply, is crucial to minimise upset conditions and resultant flaring.
- efficiency – maximising power output from the combustion of fuel gas minimises atmospheric emissions and provides a cost benefit. However, achieving maximum power output must be optimised also taking into consideration ambient temperatures and resultant NO_x emissions.
- capital cost – the purchase and installation cost of the power generating equipment is a key influencing factor that must demonstrate value.
- delivery timeframes – the production of power generating equipment are long lead items requiring a significant amount of time to construct. It is important to evaluate the length of time required to construct such equipment and whether in fact it will be available within a suitable timeframe for project execution.
- associated technical factors – consideration is also given to factors including space requirements, water consumption and emissions intensity.

From Figure 5-1 it can be seen that there are a number of power generation configurations that have been adopted for LNG plants across the world. Some have adopted aero-derivative turbines, some are considering combined-cycle gas turbines and others, such as the Pluto LNG Project, have adopted simple (open) cycle gas turbine technology with future potential to adapt waste heat recovery systems to improve efficiency if this proves of benefit (for example, if a new heat load is created during expansion).

During the design phase, the Pluto LNG Project considered several alternative technologies and power generating combinations including:

- aero derivative gas turbine generators (ADGT) (five GE LM 6000) with evaporative cooling
- industrial gas turbine generators (five GE Frame 6B)
- industrial gas turbines operating in combined cycle together with heat recovery steam generators (HRSG) and steam turbines (four GE Frame 6B plus four HRSG and two steam turbines)
- combined cycle gas turbine generators (CCGT) together with HRSG and steam turbines (four GE LM 6000 CCGTs plus four HRSG and two steam turbines)

Train 1 has carried forward the establishment of five GE Frame 6B gas turbines operating in open cycle (with waste heat recovery). The selection was made based on favourable capital costs, delivery timeframe and water consumption drivers, which significantly outweighed the benefits gained from the other evaluated power generation options. Key decision considerations are summarised in Table 6-4.

Table 6-4 Evaluation of Power Generation Technology and Operating Options based upon Indicative Data

Power Generation Option	Turbine	Avail.	Number Installed	Power Output	Efficiency* (kJ/kWh HHV)	Emissions (t/ yr) NO_x	Emissions (t/ yr) CO_2	Water Use (m^3/yr)	Capital Cost ($ M)	Delivery (mths)
5 x aero-derivative	GE LM6000	97.7%	>600	Meets requirement	10,246	325	492,150	56,180	196	18 - 20
4 x combined cycle gas turbines, plus 4 x HRSGs, plus 2 x steam turbines	GE LM6000 (in combined cycle)			Exceeds requirement	7,821	288	375,670	30,990	273	26 – 30
5 x industrial gas turbines **SELECTED**	**GE Frame 6B**	**97.1%**	**>980**	**Meets requirement**	**13,046**	**483**	**626,641**	**Nil.**	**181**	**18 - 20**
4 x industrial gas turbines, plus 4 x HRSGs, plus 2 x steam turbines	GE Frame 6B (in combined cycle)			Exceeds requirement	8,161	302	392,000	45,090	305	26 - 30

*determined from energy produced per year and fuel consumption per year.
Note: data assumes that the plant is operating at 100% MCR and does not take into account the reduction in efficiency as the plant total load is adjusted to the required system load.

Following basis of design, further evaluation was carried during detailed design to further optimise power generation. The basis of design considered five GE Frame 5 gas turbines, however following further evaluation it was determined that Train 1 power requirements can be achieved with four GE Frame 6 gas turbines. The performance of the GE Frame 5 gas turbine and the GE Frame 6 gas turbine were compared against some of the criteria identified above. The evaluation determined that significant energy efficiency benefits would be gained by adopting four of the GE Frame 6 gas turbines (**Table 6-5**). During design and the estimation of greenhouse emissions (**Section 7**), specific reference was made to the former Australian Greenhouse Office's Technical Guidelines – Generator Efficiency Standards (DEH, 2006).

It is estimated that selecting the GE Frame 6 gas turbines for the Pluto LNG Project has provided greenhouse gas emission reductions in the order of approximately 70 kg of $CO_{2\text{-}e}$ per tonne of LNG. This has also provided cost savings to the project realising a net increase on project value, when compared against the original design basis using GE Frame 5 turbines.

Table 6-5 Efficiency Comparison of Two Industrial Gas Turbine Generators – GE Frame 5 and GE Frame 6

Turbine	Type	Efficiency (%) Power Generation	Efficiency (%) Mechanical Drive
GE Frame 5	-	27.5	27.5
GE Frame 6	MS6001B	32.1	33.3

Source: GE Energy: Oil & Gas – Gas Turbine catalogue

Ministerial condition 12-1 (Item 7) requires the consideration of renewable power generating options for application to the Pluto LNG Project. This potential option is considered in **Table 6-6** against the most significant criteria stated above, namely reliability of supply and proven technology. It is important to note that Western Australia only has 333 MW of installed capacity (from 40 operating plants) across the state (DSEWPC, 2010) comprising a mixture of wind, biomass (landfill methane, woodwaste, sewage methane), solar and hydro. The largest single operating renewable power generating facility within WA is 90 MW (wind power by Infigen Energy near Geraldton) and within Australia is 1500 MW (hydro power by Snowy Hydro Ltd) (DSEWPC 2010). The nearest operating renewable power generating facility to the Burrup Peninsula is approximately 200 km to south-southeast with a capacity of 21 kW (DSEWPC 2010). This system is based at Hamersley Station and is a solar/ diesel hybrid system. The system comprises 260 solar panels and a 53 kVA diesel generator (DSEWPC 2010). Given the location of the Burrup Peninsula and geographical characteristics of the area, renewable power generation is considered impracticable to enable the safe, reliable and steady operating conditions required for a major hazard facility such as the Pluto LNG Project. For these reasons, it is concluded that renewable energy is not a plausible option for Woodside to consider at this time.

Other alternate power supply options have been considered by Woodside. Potentially significant greenhouse gas advantages can be achieved through the aggregation of power generation. Aggregating and centralising power generation will typically result in more stable load conditions which enable more energy efficient operation of generation plant. In addition, it will also be possible to reduce the number of spare generation plant required thereby reducing the overall cost of electricity. Woodside continues to explore the possibility of working in partnership or across its assets on aggregated power generation options. Woodside engaged with a third party in 2006/07 on a partnership to supply power to regional industry. Due to uncertainty surrounding the timing of the development of the other organisation's project, this opportunity was not progressed further.

Table 6-6 Evaluation of Renewable Power Supply Sources for Application to the Pluto LNG Project

Renewable Energy Type	Evaluation	Information Sources
Wind	Wind speeds sufficient to meet load requirements at ALL times throughout the day and the year are not guaranteed. Night time wind speeds usually drop below the required 'cut-in-speed' where it is then usual practice to have generation plants taken out of service until wind speeds are sufficient in the following morning. The unreliable nature of wind prevents this from being considered further.	Office of Energy (2010).
Hydro	The Dampier and Karratha region has little potential for a hydro-electric system. These are usually established on major waterways where streamflows are significant enough to harness the energy and convert it to drive turbines.	Office of Energy (2010).
Biomass	A sufficient amount of feed stock would be required to operate a biomass plant. A considerable amount of woodwaste or organic waste would need to be sourced from a local provider to allow transport and handling costs to be minimised. A 5.5 MW biomass plant proposed in NSW requires 57,700 tpa of woodwaste. This would mean, a 100 MW plant would require in the order of 1.05 Mtpa of woodwaste. No such providers exist within the Karratha-Dampier Region.	URS (2010)
Solar	Not until 2008, has Australia reached an installed capacity of 100 MW of solar generated energy. Solar thermal plants remain to be proven in Australia with many efforts in research and development, however no significant projects have been established for commercial operations in the scale of 100MW to meet industrial needs. Solar, only being available during the day-time, will also provide challenges for meeting power demands during the night-time. Photovoltaic (PV) technology has been historically cost prohibitive limiting application to small scale uses such as Remote Area Power Supply. Increasing popularity of PV systems has occurred for residential applications only as a result of government rebates.	Lovegrove and Dennis (2006). Office of Energy (2010).
Tidal	The NW of Western Australia has shown some potential for	Office of

Renewable Energy Type	Evaluation	Information Sources
	tidal power. There are a number of very small scale operations already in place (DSEWPC, 2010). However, the small range of neap tides in the northwest is usually too low to generate reliable power generation, let alone sufficient amount of power to support an LNG project.	Energy (2010).
Wave	Much of southern Australia has been recognised as potentially supporting wave energy based power generation. The minimum requirement is for coastal areas to demonstrate wave heights in excess of 1m. Wave energy has recently been introduced to Western Australia by Carnegie Wave Energy Limited who is conducting demonstration and commercialisation projects off the coast of Perth. Northern areas of Australia have been found unsuitable for wave energy technology due to lack of suitable wave conditions.	RPS MetOcean and Carnegie Wave Energy Limited (2009).

6.2.3 Acid Gas Removal Unit

The Pluto gas reservoir contains approximately 2% of naturally occurring CO_2. This CO_2 has to be removed from the LNG so that it does not freeze solid within cryogenic equipment. The Acid Gas Removal Unit (AGRU) carries out this process using solvent extraction to strip CO_2 from the natural gas stream. During the extraction process some hydrocarbon (primarily methane) is also removed. In the solvent regeneration stage the CO_2 (and hydrocarbons) stream is “flashed” (vented) to the atmosphere. Minimising the amount of hydrocarbon that is stripped from the natural gas stream therefore reduces the amount of hydrocarbon lost, thus increasing process efficiency and reducing emissions to atmosphere. To achieve this, the following two design initiatives have been carried out for the Pluto Project’s AGRU.

6.2.3.1 aMDEA Acid Gas Removal

Sulfinol was traditionally used in the solvent extraction process at Woodside LNG trains. Alternative solvent extraction processes were investigated to determine more effective processes of stripping CO_2. A more selective solvent known as activated methyl-di-ethanol amine (aMDEA) was identified and found to outperform the traditional solvent Sulfinol. The success of trials and implementation of aMDEA on other Woodside LNG trains were observed closely. Given the success, Woodside has carried forward this initiative to the Pluto LNG Project. The adopted aMDEA co-adsorbs substantially less hydrocarbon in the solvent extraction process than the Sulfinol process, thus minimising hydrocarbon loss from the AGRU.

With the use of aMDEA co-adsorption of hydrocarbons is reduced by approximately 90% and thus avoids combustion and release to the atmosphere. This is equivalent to approximately 70 kg of CO_2-e per tonne of LNG produced and in the order of 301,000 tonnes CO_2-per annum.

6.2.3.2 Flash Gas Recovery

Historically at the Karratha Gas Plant, the solvent regeneration stage in the AGRU resulted in the CO_2 (and hydrocarbons) stream being vented to the atmosphere. As discussed in Section 4.4, improvements made to the Karratha Gas Plant has allowed for this stream to be recovered and used in the fuel gas system. This same improvement has been carried forward to the Pluto Train 1. Capturing the ‘flash’ gas thereby displaces a portion of the fuel gas. Incorporation of this initiative is estimated to deliver savings in the order of 30 kg of CO_2-e per tonne of LNG produced and in the order of 129,000 tonnes CO_{2-e} per annum for Train 1.

6.2.4 Thermal Oxidiser

Gases vented from the AGRU will contain traces of BTEX along with low levels of methane. This component makes up about 1-3% of the stream, the remainder being naturally occurring reservoir CO_2 extracted from the hydrocarbon stream. Whilst independent modeling and field verification indicates that venting this stream to atmosphere is safe from an air quality and human health perspective, it is considered best practice to treat this gas stream to remove as much BTEX (and methane) as practicable, if it can be done without significant penalty (eg energy efficiency, cost etc).

A Thermal Combustion Unit (TCU) uses fuel gas to incinerate waste gas streams at high temperatures. It is the simplest and most reliable means to achieve this. A TCU achieves ~99% BTEX (benzene, toluene, ethylbenzene and xylene) destruction. A TCU has been used in other Woodside Trains, specifically Trains 4 and 5 of the Karratha Gas Plant. An analysis of alternate technology and efficiency by Woodside identified the potential to remove the traditional TCU but still destroy a very high proportion of the trace BTEX using a Regenerative Thermal Oxidiser (RTO). A RTO uses significantly less fuel gas than a TCU. A ceramic bed within the reaction chamber retains the heat of hydrocarbon oxidation and only a small amount of fuel gas is required during start-up and operation. This alternative will result in a reduction in greenhouse gas emissions in the order of 6kg of CO_2-e per tonne of LNG produced and in the order of 25,800 tonnes CO_{2-e} per annum. It also has two benefits over installing no post-treatment, as both BTEX and residual methane (a more potent greenhouse gas than carbon dioxide) is largely combusted for a small fuel gas penalty.

6.2.5 Waste Heat Recovery

Waste heat usually emitted from process units such as power generation and liquefaction, is a useful energy source captured and directed back into the process. The energy (in the form of heat) can displace the need for generating that same amount of energy for other heat-users by combusting fuel gas. Recovering waste heat reduces unnecessary energy loss, allows energy to be reused and results in less fuel being burnt, therefore improving the efficiency of the LNG process.

To enhance the efficiency of the LNG process, waste heat will be recovered as follows:

- **Power Generation:** required waste heat will be recovered from the power generation turbines. Two of the four Frame 6 turbines are fitted with waste heat recovery units.
- **Liquefaction:** waste heat will be recovered from the Frame 7 propane compressor turbine, which is fitted with a waste heat recovery unit.

Waste heat from these two sources is combined into a common hot water circuit and utilised in various process areas. It estimated that the total waste heat requirement will be between 85 and 100MW, principally to supply process heating to the AGRU and MEG Regeneration systems and this is met by the waste heat recovery capacity installed.

The use of waste heat in these process areas displaces the need to install boilers to meet these heating requirements and as such reduced fuel gas consumption. Based on displacing gas fired boilers, approximately 20 kg of CO_2-e per tonne of LNG produced or 86,000 tonnes CO_2-e per annum are saved through waste heat recovery.

6.2.6 Tandem Dry Gas Seals

The LNG process requires several stages of compression and expansion of gases to extract heat from the hydrocarbon stream and liquefy it into LNG. Compressors contact moving parts that must be effectively sealed from the external environment. Several sealing technologies are available; however dry gas seals result in the lowest emissions of all currently available sealing technologies. They can be configured in a number of ways, one of which (face-to-face) uses high pressure buffer gas to eliminate process gas emissions. Buffer gas is generally nitrogen. In some configurations it can be expected that some will leak across the primary seal into the process. This is not acceptable for closed loop refrigeration systems. Hence a tandem dry gas seal arrangement is considered best available technology to minimise, as far as practicable, methane leakage from the main refrigeration loops and this has been incorporated within the basis of design. This significantly improves upon technology previously adopted for the Karratha Gas Plant trains, which utilise free-venting oil seals passing methane to atmosphere for Trains 1 to 3, with vapour recovery on Trains 4 to 5. This design feature has enabled Karratha Gas Plant Trains 1 to 3 to avoid venting losses at approximately 317 tCH_4 per month, equating to a greenhouse emission saving of 26,700 tCO_{2-e} per annum based on production of 2.5 MTPA.

Adopting this design feature for Pluto Train 1 will avoid approximately 182 tCH_4 per month (pro-rata from Karratha Gas Plant performance and production) equating to a greenhouse emission saving of approximately 39,460 $tCO_{2\text{-}e}$ per annum based on production of 4.3 MTPA.

6.2.7 Optimising Nitrogen Content in the Fuel Gas

Optimising nitrogen content in the fuel gas reduces greenhouse gas emissions, where a supply of high purity nitrogen is available. As gas from the Pluto reservoir contains a moderate proportion of nitrogen, its compulsory removal during the liquefaction process enables its use in the gas turbines with little additional cost or efficiency penalty relating to supply.

Increased nitrogen composition in the combustion gas reduces the Wobbe Index[3]. This in turn increases the power output of the turbine, over less lean gas.

6.2.8 Floating Roof Condensate Storage Tanks

Condensate tanks come in two generic configurations – floating roof and fixed roof, with variations on each theme with respect to emission and contamination control. Floating roof tanks represent a higher capital investment against a fixed roof tank and results in substantively less hydrocarbon loss as a result of diurnal breathing. For new-build fixed roof tanks, it is common practice and industry best practice respectively to direct breathing losses to flare or vapour recovery. Where vapour recovery is not installed, breathing losses directly correlates to an increase in greenhouse emissions as C4+ hydrocarbons are flared to CO_2. Where vapour recovery is installed, some greenhouse emissions are still generated to produce power to run the vapour recovery system.

For larger-scale storage of condensates like the Pluto LNG Project, floating roof tanks, whilst venting small volumes of residual, heavier chain hydrocarbons, have minimal breathing losses, do not have an ongoing power demand and emit little to no greenhouse gas (i.e. methane). Floating roof tanks, along with fixed roof tanks with vapour recovery, are considered best available technology at not excessive cost.

6.2.9 Nitrogen Flare Purging

Based on the composition of the Pluto gas fields, nitrogen from the reservoir will be produced as a by-product of the LNG process. A nitrogen removal unit (NRU) is required to remove nitrogen from the LNG stream. Nitrogen is useful throughout the plant to purge vessels and flare systems and operate instrumentation. Whilst this could be generated from air (79% N_2), this would require additional energy when a very rich N_2 stream is already being generated by the facilities.

In 2006, Woodside completed an investigation into flare gas reductions. A key finding of this was that approximately 1,200 $tCO_{2\text{-}e}$ per annum (300t per flare) could be saved if a substitution to fuel gas purging of the flare systems could be implemented. An opportunity to use a portion of the produced nitrogen was identified to substitute flare gas and this has been carried forward into the Pluto Project's Train 1 design. The nitrogen system is designed to supply the maximum requirements of nitrogen continuously to purge the four flare systems on site (Site A: storage and loading flare, Site B: cold-dry flare, warm-wet flare and spare flare).

6.2.10 Main Cryogenic Heat Exchanger Redesign

Leakage experienced within the main cryogenic heat exchanger (MCHE) on the Karratha Gas Plant Train 4 liquefaction train has resulted in flaring of the order of 80 tonnes of gas per day, corresponding to emissions of 73,000 $tCO_{2\text{-}e}$ annually.

[3] A Wobbe Index is an indicator of the interchangeability of fuel gases and is used to compare the combustion energy output of different composition gases fuel in an appliance.

Woodside has worked with Shell and Linde (the MCHE supplier and technology owner) to redesign the MCHE bundle, with the intent of eliminating the main causes of leakage associated with the KGP Train 4 MCHE. As this is a modified design and will be the first instance of this design being implemented, operating experience will determine if the Pluto MCHE outperforms current KGP Train 4 performance. If the modified design is successful, it is expected that greenhouse gas emissions that may otherwise have been emitted will be avoided.

6.2.11 Specification of High Efficiency Motors

High efficiency motors have been specified as a minimum requirement for the basis of design and procurement for the development of Train 1. Whilst detailed calculations have not been made for each and every application, this will result in energy (and hence greenhouse) savings of several percent per motor, across the full facility. High efficiency motors are considered best available technology.

6.2.12 Relief Valve Minimisation

Throughout FEED, mechanisms by which relief valves can either be eliminated or, if this is not practicable for safety and economic reasons, sent to flare have been investigated. Whilst the reductions in released gas may not be significant in comparison to major design abatement measures, reduction of vented methane results in approximately eight times less ‘greenhouse effect’ (relative to global warming potentials) for these emissions than would eventuate from ‘business as usual’.

6.2.13 Boil-Off Gas Compressor Redundancy

The Pluto boil off gas system on the LNG storage and loading system includes two parallel compressors to handle both normal operation (holding) and ship loading situations:

- 1 x 100% boil off gas compressor, 1 x 100% boil off gas compressor on standby (holding mode)
- 2 x 50% boil off and vapour return compressors (ship loading mode).

This significantly reduces the potential for boil-off gas needing to be flared during holding mode, as a spare compressor is usually available (loading occurs for less than 20% of Train 1 operations). If one compressor trips, the other compressor will automatically start. In the event that a compressor trips during ship loading mode, flaring will occur but at reduced rates (given a 50% compressor will still be running) to what would occur if only one compressor was installed.

6.3 Beyond No Regret Mitigation Measures

Table 6-7 summarises the main “beyond no regret” greenhouse reduction initiatives implemented for Train 1 of the Pluto LNG Project, including an estimate of the annual greenhouse reductions achieved. Further detail around each initiative is provided in the following sub-sections.

Table 6-7 Summary of “Beyond No Regret” Greenhouse Abatement Initiatives for the Pluto LNG Project

Abatement Opportunity	* GHG savings (tCO_{2-e}) p.a.	GHG savings (tCO_{2-e} / tLNG)	Comments / Assumptions
Trunkline Onshore Terminal Modifications	1-2	0	Pigging frequency is based on several factors, thus a range is provided.
Market Offsets	242,000	0.065	Contract with CO2Australia to offset reservoir CO_2 emissions

*Based upon LNG production of 4.3 Mtpa (w/avail)
#Annual emissions assumed constant for 20 years.

6.3.1 Trunkline Onshore Terminal Modifications

The present KGP trunkline onshore terminal (TOT) pig launcher/receiver must be vented to atmosphere each time the trunklines are pigged. In addition, the pig launcher is not rated for trunkline pressure and as such must vent to ensure safe conditions are maintained if gas passes from the trunkline to the launcher. To improve on this design for Pluto, the following initiatives have been implemented:

- whilst depressurisation of the launcher/receiver is still required to allow opening of the vessel, gas is directed to flare, resulting in lower greenhouse intensity.
- the Pluto TOT has been fully rated for trunkline pressure and, as such, relief valves have been removed.

The greenhouse gas savings of this initiative will vary with pigging frequency and are small in comparison to the overall greenhouse footprint of the plant, however are entirely based on improving design integrity (for safety) and decrease emissions of methane to atmosphere (and hence greenhouse emissions) and represents “beyond no regret”.

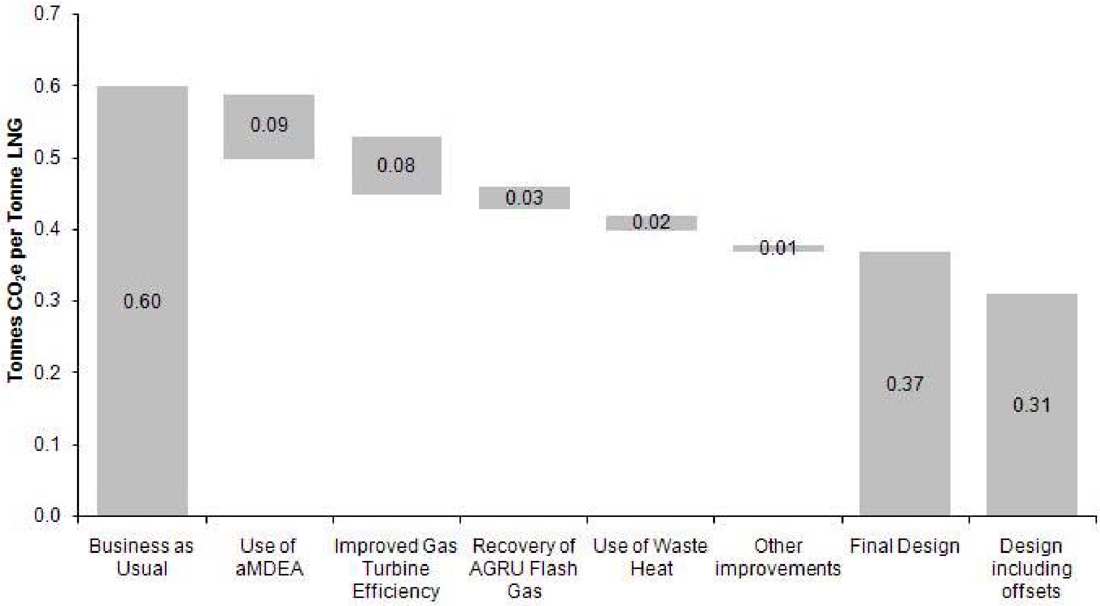
6.3.2 Offsets

Offsets have been adopted for the Pluto LNG Project Train 1 reservoir CO_2. This is not specifically a design mitigation measure and is therefore discussed separately in **Section 9**, but it does represent a significant “beyond no regrets” cost to the project that can not at present be recovered.

6.4 Summary of "No Regret" and "Beyond No Regret" Initiative Improvements

Figure 6-1 illustrates the improvements that have been achieved from the 'Business as Usual' base case as Woodside has progressively developed more efficient LNG projects.

Figure 6-1 Greenhouse Gas Emissions Efficiency Improvements



7 Greenhouse Gas Emissions Profile

7.1 Overview

This section details the greenhouse gas emissions profile for the life of Train 1 of the Pluto LNG Project and outlines briefly the methodology, including key data inputs required to estimate the greenhouse emissions. The emission profile for onshore components of the LNG facility include:

- Acid gas removal unit (AGRU)
- Liquefaction
- Nitrogen removal unit (NRU)
- Power generation (gas)
- Power generation (emergency – diesel)
- Flaring
- Fugitives

7.2 Method of Estimation

For the purposes of estimating greenhouse emissions the following key documents were utilised as guidance material:

- Methods for Estimating Atmospheric Emissions from E&P Operations: Report No. 2.59/197 (OII E&P Forum, 1994)
- Calculating Greenhouse Gas Emissions (CAPP, 2003)
- Technical Guidelines - Generator Efficiency Standard (DEH, 2006).

Emission estimates were based upon functions of the following key data inputs:

- Stream characteristics and compositions
- Stream flow rates
- Molar flow rates and mass
- Heat mass balance
- Production profile for the life of the LNG plant
- Fuel consumption profile for the life of the LNG plant

Where technical data was not sufficient to predict greenhouse emissions, emission factors were used. For example, emissions from the combustion of diesel were estimated by utilising emission factors from the OII E&P Forum (1994).

7.3 Estimated Emissions

7.3.1 Greenhouse Gas Emissions Profile

The emissions profile for onshore components of the Pluto LNG Project (Train 1) is provided in Table 7-1 The emissions for Pluto LNG Train 1 and associated onshore equipment will be approximately 1.61 Mt CO_{2e} per annum. Over the life of the project, total emissions will be approximately 33.9 Mt CO_{2e}. The majority of emissions are derived from the liquefaction unit, power generation and AGRU.

Table 7-1 Greenhouse Emissions Profile for Onshore Components of the Pluto LNG Project

Category	Emission Sources	Total lifetime Emissions ('000 t CO_2e)	Avg. Emissions Per Year ('000 CO_2e tpa)
Onshore	AGRU	5,100	242
	Liquefaction	16,890	804
	NRU	134	6
	Power Generation (Gas)	11,096	528
	Power Generation (Emergency Diesel)	3	0.1
	Flaring	586	29
	Fugitives	87	4
TOTAL (Mt CO_2e)		**33.9**	**1.61**

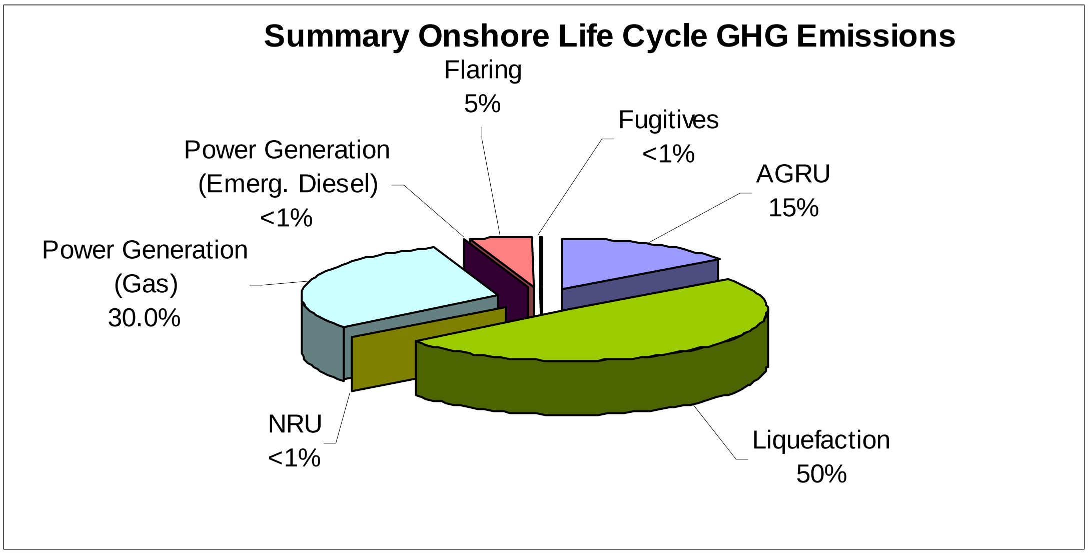


Table 7-2 Onshore Greenhouse Gas Emission Sources for Project Life

7.3.2 Emission Offsets

Woodside has committed to offset emissions to atmosphere of reservoir CO_2 that will be extracted from hydrocarbons during liquefaction. Reservoir CO_2 emissions and thus committed offset equates to approximately 242,000 tCO_2 per annum. Although this is discussed further in **Section 9**, the offset reduces the Project's annual greenhouse emissions by about 15% to 1.37 MtCO_{2e} per annum. Over the lifetime of the project, approximately 5.1 Mt will be offset reducing "total" onshore emissions from Train 1 to 28.8 Mt CO_{2e}.

7.4 Comparison of Greenhouse Emissions to National and State Inventories

A comparative analysis of the estimated emissions with and without offsets against national and state greenhouse gas inventories from 1990 and recently is presented in **Table 7-3**. Train 1 contributes less than 1% of national emissions and approximately 2 – 3% of state emissions.

Table 7-3 Pluto LNG Greenhouse Emissions compared to National and State Emissions

Component	Mtpa (CO_{2-e})	% relative to national emissions		% relative to state emissions	
		1990	2010	1990	2008
Australia 1990 emissions	552	-			
Australia 2010 emissions^	542	-			
Western Australia 1990 emissions	57.3	-			
Western Australia 2008* emissions	72.8	-			
Train 1 onshore – annual emissions (no offsets)	1.61	0.29	0.30	2.8	2.23
Train 1 onshore – annual emissions (with offsets)	1.37	0.25	0.25	2.39	1.88

^ Annual emissions through to March quarter 2010. Estimate does not include emissions from Land Use, Land Use Change and Forestry Activities.

*Western Australia's greenhouse gas inventory for 2009 or 2010 is not available.

Source: DEH (2006), DCCEE (2010).

8 Greenhouse Gas Mitigation – Future Opportunities

8.1 Overview

This section provides a current indication of potential future opportunities that may exist for further reducing greenhouse gas emissions from Train 1. It must be recognised that prior to any further greenhouse gas reduction measures being applied, Woodside will firstly place priority on validating the performance (and emissions) of the operation. To date, predictive models and estimation techniques have been used to predict estimated emissions. Validating these predictions and the performance of the newly operating equipment will be important in establishing the plant's baseline greenhouse emissions for its first year of operation.

Thereafter, the performance of the plant can be evaluated and the highest value opportunities to generate greenhouse reductions (and thus set reduction targets) can be established.

This section therefore focuses on a number of plant performance reviews that will be undertaken for the plant's first year of operation.

8.2 No Regret Measures

8.2.1 Energy Efficiency Reviews

Woodside carries out regular energy efficiency reviews across its operations as standard operating practice to continually improve energy efficiency, reduce greenhouse gas emissions and optimise performance of its facilities. Some highlights of previous energy efficiency reviews have been previous discussed in **Section 4.4**.

Energy efficiency reviews will be carried out for the Pluto LNG Project. From these reviews it is anticipated that a number of improvements may be identified and implemented to reduce energy consumption and hence greenhouse emissions. Aspects of the plant that would be typically reviewed include:

- Power generation efficiency and optimisation;
- Waste heat recovery and re-use of waste heat;
- Ancillary equipment such as electric motors, pumps and air compressors and potential to fit variable speed drives or high efficiency motors;
- Efficiency of buildings and work spaces.

To enable energy efficiency reviews, Woodside has implemented comprehensive metering and data recording systems to capture the required information. This enables Woodside to continually monitor the energy efficiency performance of the plant as improvement opportunities are implemented.

8.2.2 Flare Gas Recovery Study

Following the plant's first year of operation a flare gas recovery study will be undertaken to review operations and identify potential opportunities to further minimise and identified leakage and unplanned flaring volumes and frequencies.

8.3 Beyond No Regret Measures

8.3.1 Geosequestration

Woodside continually reviews new technology to reduce greenhouse emissions. Carbon geosequestration is one technology that has potential application to the LNG industry. Carbon geosequestration would involve recovering a concentrated CO_2 stream, compressing the CO_2 to a supercritical state and injecting it into a suitable subsurface reservoir.

Process technology adopted for the LNG Plant currently removes the naturally occurring CO_2 from the feed gas. The concentrated CO_2 resulting from this process is a candidate for geosequestration. Potential reservoirs for geosequestration include the Wandoo, Harriet-Campbell group of fields and the North-Rankin Goodwyn fields. However, all of these reservoirs are located in excess of 60 km from the Burrup Peninsula which would require a subsea trunkline to transport the CO_2. These fields are currently producing oil and gas fields, and for this reason are not accessible for geosequestration at this time. In the case of the Wandoo, Harriet-Campbell group of fields, they are also held under licences by other operators. As a result, these fields would not be available for geosequestration until later in the life of the Pluto LNG Project and only subject to agreeing access arrangements in the case of reservoirs held under licence by other operators.

The reservoir CO_2 generated through liquefaction of gas from the Pluto gas field contributes approximately 15% of total emissions from the plant. The capital cost of geosequestration including onshore compression and liquefaction equipment, pipelines, pumps, wells and injection is expected to be in the order of AU$500 million. The total cost of abatement is therefore in the order of $100 per tonne of $CO_{2\text{-}e}$. This is not considered a reasonably practicable option when assessed against both business economic hurdles and viable alternatives to offset emissions. Notwithstanding this, Woodside is committed to continually review the application of geosequestration for future LNG projects should feasibility improve in the areas of cost, liquefaction and reinjection technology.

8.3.2 Fugitive Emissions

Fugitive emissions contribute an estimated 0.25% of total LNG plant emissions. Although this is a small proportion, fugitive emission leaks to atmosphere and to flare, representing a manageable element of emissions from the facility. A targeted and effective leak detection and repair (LDAR) program is an efficient means of minimise these sources to as low as reasonably practicable. A LDAR program will be developed and implemented for the facility in line with industry good practice.

9 Greenhouse Gas Offsets

9.1 Carbon Sequestration

Carbon sequestration will be adopted for Train 1 by utilising bio-sequestration (planting of oil mallee trees). Woodside has established an extensive bio-sequestration project through CO2Australia to offset the reservoir CO_2 from the Pluto gas field that will feed Train 1. Woodside will offset 242,000 tCO_{2-e} per annum to a total of approximately 5.1 Mt CO_{2-e} for the life of Train 1.

CO2 Australia is one of the largest providers of dedicated forest carbon sink plantings with up to 16,500 hectares of tree planting projects across New South Wales, Victoria and Western Australia (CO2Australia, 2009). CO2Australia's Carbon Sequestration Program is accredited under the Australian Federal Government's former Greenhouse Friendly(TM) Program and is Kyoto Protocol compliant (CO2Australia, 2009).

Oil mallees are the preferred species of tree for biosequestration purposes as they have been subject to significant study by CSIRO and Future Farm Industries CRC. These studies have highlighted numerous other benefits of oil mallee plantings including (Smith, not dated):

- increase on-farm biodiversity;
- natural pest control through increased native predators;
- additional livestock shelter;
- improved soil protection; and
- establishment of wildlife habitats.

Potential opportunities for geo-sequestration have been reviewed by Woodside for the Pluto LNG Project and are currently considered unviable. Geo-sequestration is discussed in **Section 8.3.1**.

10 Targets, Monitoring, Auditing and Reporting

10.1 Targets

The initial target for greenhouse efficiency is to verify that the design efficiency of the plant is being achieved or bettered. As such, the primary objective of the initial years of operational monitoring will be to verify plant performance against design estimates. Monitoring, auditing and reporting of greenhouse gas emissions for Train 1 will be the primary mechanism for measuring plant performance and transparently demonstrating this performance.

Monitoring, auditing and reporting for Train 1 will be carried out in accordance with the requirements of the *National Greenhouse and Energy Reporting Act 2007*.

10.2 Monitoring

This Greenhouse Gas Abatement Program will be monitored on an ongoing basis. During monitoring, actions may be identified for ongoing improvement. These will be tracked as part of the Pluto LNG Project's Greenhouse Gas Improvement Plan (refer to **Section 11**).

Monitoring activities will be aligned with those required under the Pluto air emissions monitoring programme required under Ministerial condition 11-2 (item 3), as well as standard practice production and fuel consumption monitoring.

10.3 Auditing

Auditing of the environmental and greenhouse performance of Train 1 will be implemented via the following mechanisms:

- Internal and external environmental audits of Woodside's environmental management systems and compliance to its statutory obligations and management plans;
- External auditing (as required) of greenhouse data reporting as required under the *National Greenhouse Energy Reporting Act 2007*;
- External verification (as required) of energy efficiency assessments and reporting as required under the *Energy Efficiency Opportunities Act 2006*. Woodside is a member of the Energy Efficiency Opportunities program which requires large businesses to identify, evaluate and report publicly on cost effective energy savings opportunities. Under this program the Department of Resources, Energy and Tourism conducts verification to:

  - validate corporations' compliance with EEO legislation when conducting energy assessments, identifying opportunities and reporting outcomes
  - monitor whether a corporation has carried out its energy efficiency assessment as set out in its own approved Assessment and Reporting Schedule (ARS)

10.4 Reporting

Woodside currently carries out reporting to meet a number of statutory requirements. Woodside will address greenhouse emission reporting via existing procedures established to meet the requirements of the *National Greenhouse Energy Reporting Act 2007* and the *Energy Efficiency Opportunity Act 2006*.

Compliance with the actions and requirements of this Greenhouse Gas Abatement Programme will be reported through the Annual Compliance Reporting requirements specified in Ministerial conditions (item 4-1).

10.4.1 National Greenhouse and Energy Reporting

The *National Greenhouse Energy Reporting Act 2007* was introduced to:

- Inform government policy formulation and the Australian public
- Help meet Australia's international reporting obligations

- Assist Commonwealth, state and territory government programs and activities
- Avoid the duplication of similar reporting requirements in the states and territories

Woodside is required to carry out greenhouse reporting for the Pluto LNG Project. This will be carried out to meet the requirements of the Act. As an example of Woodside's current reporting for other facilities, the following greenhouse gas emission sources are included in annual reports:

- use of fuel gas (unprocessed natural gas) for electricity generation and other stationary energy sources
- flaring of natural gas in operational and safety flares
- fugitive loss of any gaseous fuel source or energy commodity that is one of the six listed greenhouse gases defined in the NGER Act (including fugitive emissions associated with leaks)
- use of crude oil for electricity generation
- diesel use for stationary energy and transportation purposes
- gasoline (unleaded fuel use) for transportation
- sulphur hexafluoride leakage from gas insulated switchgear and circuit breakers

10.4.2 Energy Efficiency Opportunities Reporting

Woodside is required to report annually under the *Energy Efficiency Opportunities Act 2006* on the following aspects as a minimum:

- energy use;
- amount of energy savings;
- at least three significant energy efficiency opportunities identified during an assessment, including a description of the opportunity, costs of implementation and ongoing savings in regard to energy use; and
- cumulative information showing the progressive improvement from year to year of implemented energy efficiency opportunities.

10.4.3 Greenhouse Challenge

Woodside has been a member of the Greenhouse Challenge since 1995 up until the cessation of the Program in July 2009. The Program is no longer active and as a result, industry participation has ceased.

11 Greenhouse Gas Performance Improvement Plan

The following Greenhouse Gas Improvement Plan is provided based upon current knowledge and activities planned for the first two years of operation of Train 1 and achieving steady state operations. The Improvement Plan will be internally reviewed annually and updated to reflect any additional initiatives that might be identified during the preceding year's operational experience.

The following table lists the activities, as identified to date, that will be undertaken for Train 1.

Table 11-1 Pluto Train 1 Greenhouse Gas Improvement Plan (Start Up – First Two Years of Steady State Operations)

Ref No.	Task	Purpose	Output	Timing
1	Monitor atmospheric emissions, energy consumption and LNG production	Validate existing emission estimates, greenhouse predictions and design criteria or understand any variance	Establish baseline emission estimates and greenhouse intensity	First year of steady state operations
2	Undertake a Leak Detection and Repair Program	Minimise emission losses and maximise operational efficiency	Recommendations for minimising leaks	First year of steady state operations
3	Undertake a Flare Gas Recovery Study	Maximise operational efficiency	Recommendations for gas recovery	Second year of steady state operations
4	Undertake an energy efficiency review of the plant	Maximise operational efficiency and improving plant performance and emissions intensity	Establish a revised (reduction) target for greenhouse intensity and make recommendations for improving energy efficiency	Within 18 months of steady state operations
5	Identify energy efficiency gains and improved greenhouse emissions intensity by integrating systems for future expansion	Maximise operational efficiency and improve emissions intensity	Revised cumulative emissions estimates and greenhouse intensity	In parallel with Pluto expansion plans
6	Continue to monitor market abatement opportunities	Maximise efficiency of global greenhouse gas reduction efforts for any additional Pluto offsets	Understanding of market offset opportunities for business evaluation	Within 18 months of steady state operations
7	Review Greenhouse Gas Improvement Plan and incorporate any identified actions	Maintain a "live" improvement plan	Annual review and incorporation of identified initiatives where appropriate	Around the anniversary of steady state operations, annually
8	Review and update the Greenhouse Gas Abatement Program	Maintain transparency over Woodside's greenhouse gas efficiency performance on the Pluto LNG Project	Updated Greenhouse Gas Abatement Plan.	5 years from steady state operations, or prior to commissioning of new trains

12 Management Review

This Greenhouse Gas Abatement Program will be formally reviewed and updated every five years as a minimum or prior to the commissioning of additional LNG trains at Pluto. Where either the five yearly review cycle or additional infrastructure review cycle is triggered, a revised Greenhouse Gas Abatement Program will be submitted to the Environmental Protection Authority in accordance with Ministerial Statement No. 757.

13 References

Australian Petroleum Production and Exploration Association Limited (APPEA), November 2010. Climate Change Policy Principles. Draft. A Government/ Industry Partnership for Cleaner Energy Future.

Chevron Australia 2008. Public Environmental Review for the Gorgon Gas Development Revised and Expanded Proposal.

Chevron Australia, July 2010. Draft EIS/ERMP for the Proposed Wheatstone Project.

CO2 Australia, 2009. Carbon Sequestration. http://www.co2australia.com.au/index.php?action=news&nid=1483, accessed 30 November 2010.

ConocoPhillips 2005. Darwin 10 Mtpa LNG Facility Public Environmental Review. http://www.conocophillips.com.au/EN/responsibilities/health/environment/dlng%20emp/Pages/index.aspx

Co-ordinator General, May 2010. Co-ordinator-General's Evaluation report for an EIS - Gladstone Liquefied Natural Gas - GLNG Project. http://www.dip.qld.gov.au/resources/project/curtis-lng/queensland-curtis-lng-project-cg-report.pdf"

DCCEE – see Department of Climate Change and Energy Efficiency

DEH – see – Department of Environment and Heritage

Department of Climate Change and Energy Efficiency, July 2010. National Greenhouse Accounts (NGA) Factors. http://www.climatechange.gov.au/publications/greenhouse-acctg/national-greenhouse-factors.aspx, accessed 26 October 2010.

Department of Climate Change and Energy Efficiency, August 2010. Australian National Greenhouse Accounts. Quarterly Update of Australia's National Greenhouse Gas Inventory – March Quarter 2010. Commonwealth of Australia.

Department of Environment and Heritage, May 2006. National Greenhouse Gas Inventory 2004. Australian Greenhouse Office. Kyoto Accounting Framework.

Department of Environment and Heritage, December 2006. Technical Guidelines – Generator Efficiency Standards. Australian Greenhouse Office.

Department of Sustainability, Environment, Water, Population and Communities, 2010. Map of operating renewable energy generators in Australia. http://www.ga.gov.au/renewable/, accessed 4 November 2010.

DSEWPC – see Department of Sustainability, Environment, Water, Population and Communities

Lampard, M, et al. 2010. Minerals and energy, major development projects – April 2010 listing, ABARE, Canberra, May 2010.

Lovegrove, K and Dennis M, 2006. Solar thermal energy systems in Australia. International Journal of Environmental Studies, 63:6, pp 791-802. http://solar-thermal.anu.edu.au/wp-content/uploads/IJES06.pdf, accessed 8 November 2010.

Office of Energy, 2008. Energy WA, Installed Electricity Generation Capacity. August 2008.

QGC Ltd, 2009. Queensland Curtis LNG Project (QCLNG) Environmental Impact Statement. http://qclng.com.au/eis/draft-eis/

RPS MetOcean and Carnegie Wave Energy Limited (2009). Australia Baseload Wave Energy Resource. http://www.carnegiewave.com/index.php?url=/ceto/base-load-wave-power#, accessed 8 November 2011.

Santos Ltd, March 2009. Gladstone LNG Environmental Impact Statement. http://www.glng.com.au/Content.aspx?p=90

Shell Development (Aus) Pty Ltd, 2009. Prelude Floating LNG Project. Draft Environmental Impact statement. EPBC 2008/4146. October 2009. http://www.shell.com/static/aus/downloads/about_shell/prelude/completeeisdoclowres.pdf

Smith, P. Not dated. Biodiversity benefits of oil mallees. Fact sheet. http://www.co2australia.com.au/files/Biodiversitybenefitsofoilmallees.pdf, accessed 30 November 2010.

Statoil (2009) Sustainability Report http://www.statoil.com/annualreport2009/en/sustainability/keysustainabilityperformancedata/hseaccounting/environmentaldata/pages/sn%C3%B8hvitlnginstallation.aspx

Tangguh LNG (2005) Summary Environmental Impact Assessment. http://www.adb.org/documents/environment/ino/ino-tangguh-lng-project.pdf

Woodside, 2006. Pluto LNG Development. Draft Public Environment Report/ Public Environmental Review. December 2006.

Woodside, 2006. Pluto LNG Development. LNG Contractor/ Technology Evaluation Report. Confidential. DRIMS# 2619533.

Woodside, 2009a. Sustainable Development Report 2009. www.woodside.com.au.

Woodside 2009b. Pluto LNG Project. Greenhouse Gas Management Plan. Unpublished report. DRIMS# 3298947.

Worley Parsons (2010) Australia Pacific LNG Project Environmental Impact Assessment, Volume 5, Attachment 31 “Greenhouse Gas Assessment – LNG Facility”.

Yost, C., and DiNapoli, R., 2003. Benchmarking Study Compares LNG Plant Costs. The Oil and Gas Journal 101 (15), 56-59.

URS, 2010. Environmental Assessment. South East Fibre Exports 5.5 MW Biomass Power Plant. Volume 1 – Main Report; Project Description Chapter. Prepared for South East Fibre Exports Pty Ltd. http://majorprojects.planning.nsw.gov.au/files/48787/02.%20Project%20Description.pdf, accessed 8 November 2010.