Gorgon Gas Development and Jansz Feed Gas Pipeline

Air Quality Management Plan

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1 Introduction

1.1 Proponent

Chevron Australia Pty Ltd (CAPL) is the proponent and the person taking the action for the Gorgon Gas Development on behalf of the following companies (collectively known as the Gorgon Joint Venturers):

- Chevron Australia Pty Ltd
- Chevron (TAPL) Pty Ltd
- Shell Development (Australia) Pty Ltd
- Mobil Australia Resources Company Pty Limited
- Osaka Gas Gorgon Pty Ltd
- Tokyo Gas Gorgon Pty Ltd
- JERA Gorgon Pty Ltd.

1.2 Project

CAPL is developing the gas reserves of the Greater Gorgon Area. The gas will be processed in a gas treatment plant on Barrow Island, which is located off the Pilbara coast 85 km north-north-east of Onslow in Western Australia (WA) (Figure 1-1).

Subsea gathering systems and pipelines deliver feed gas from the Gorgon and Jansz–Io gas fields to the west coast of Barrow Island. The underground feed gas pipeline system then traverses Barrow Island to the east coast where the Gas Treatment Plant (GTP) is located. The GTP includes natural gas trains that produce liquefied natural gas (LNG) as well as condensate and domestic gas. Carbon dioxide, which occurs naturally in the feed gas, is separated during the production process and injected into deep rock formations below Barrow Island. The LNG and condensate is loaded onto tankers from a jetty and then transported to international markets. Gas for domestic use is exported by pipeline from Barrow Island to the domestic gas collection and distribution network on the WA mainland.

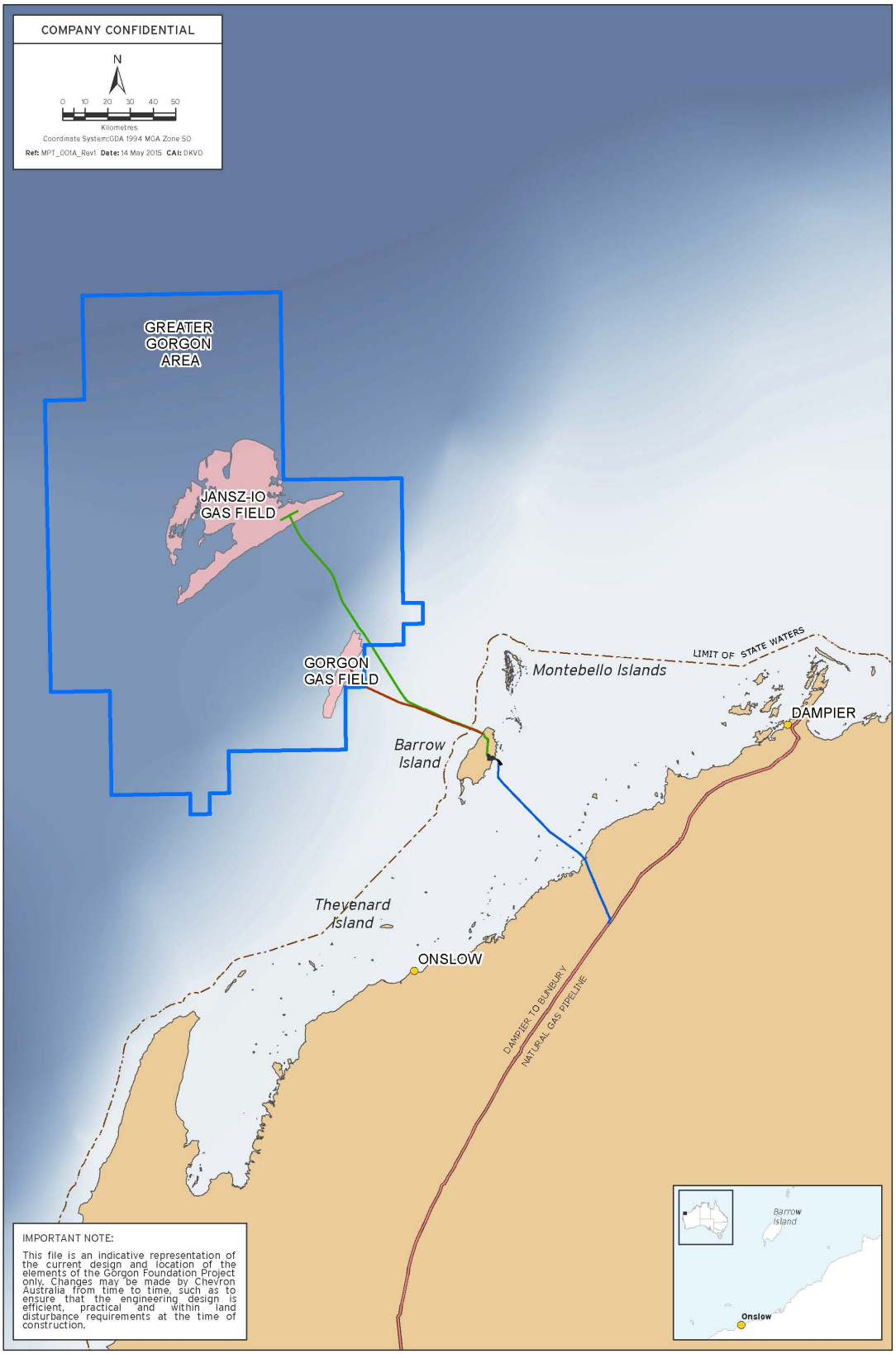


Figure 1-1: Location of Barrow Island and the Greater Gorgon Area

1.3 Approvals

Table 1-1 describes State (WA) and Commonwealth (Cth) approvals for the components of the Gorgon Gas Development.

These approvals, and projects as approved under these approvals, have been and may continue to be amended (or replaced) from time to time.

Table 1-1: State and Commonwealth Approvals

Project Approval Stage	State	Commonwealth
Jansz Feed Gas Pipeline	Ministerial Statement (MS) 769 (Ref. 1) 28 May 2008	EPBC Reference: 2005/2184 (Ref. 2). 22 March 2006
Initial Gorgon Gas Development (2 LNG Trains)	Initial Gorgon Gas Development comprising two LNG Trains – MS 748 (Ref. 3). This was superseded by MS 800 (Ref. 4). 6 September 2007	Initial Gorgon Gas Development comprising two LNG Trains – EPBC Reference: 2003/1294 (Ref. 5). 3 October 2007
Revised and Expanded Gorgon Gas Development (3 LNG Trains)	MS 800 (Ref. 4) provides approval for both the initial Gorgon Gas Development and the Revised and Expanded Gorgon Gas Development (compromising three LNG Trains). This statement supersedes MS 748. 10 August 2009	The Revised and Expanded Gorgon Gas Development (EPBC Reference: 2008/4178 [Ref. 6]) was approved, and the conditions for the initial Gorgon Gas Development (EPBC Reference: 2003/1294 [Ref. 5]) were varied. 26 August 2009
Dredging Amendment	MS 865 (Ref. 7) provides approval to establish a restart mechanism in the event of a project-attributable coral health management trigger. This statement is an amendment to Conditions 18, 20, and 21 of MS 800. 8 June 2011	Not applicable (N/A)
Additional Support Area	MS 965 (Ref. 8) applies the conditions of MS 800 to an Additional Support Area. 2 April 2014	The conditions for the initial Gorgon Gas Development (EPBC Reference: 2003/1294 [Ref. 5]).and for the Revised and Expanded Gorgon Gas Development (EPBC Reference: 2008/4178 [Ref. 6]) were varied. 15 April 2014
Fourth Train Expansion[1]	MS 1002 (Ref. 9) applies the conditions of MS 800 to the Fourth Train Expansion, and has additional conditions. 30 April 2015	EPBC Reference: 2011/5942 (Ref. 10). 12 May 2016

1.4 Purpose of this Plan

1.4.1 Requirement for this Plan

This Plan is required under Condition 29 of MS 800:

> *'The Proponent shall submit to the DEC as part of its Works Approval application for the Gas Treatment Plant an Air Quality Management Plan (the*

[1] This Plan applies to the Fourth Train Expansion once this scope commences.

Plan) that meets the objectives of Condition 29.2 and the requirements of Condition 29.3.'

This Plan was submitted to the Western Australian Department of Environment and Conservation (DEC; now known as the Department of Water and Environmental Regulation [DWER]) as part of CAPL's Works Approval application for the GTP.

1.4.2 Objectives of this Plan

The objectives of this Plan, as stated in Condition 29.2 of MS 800 are to:

i. *ensure air quality meets appropriate standards for human health in the workplace*

ii. *ensure air emissions from the Gas Treatment Plant operations do not pose a risk of Material or Serious Environmental Harm to the flora, vegetation communities, fauna, and subterranean fauna of Barrow Island.*

1.4.3 Contents of this Plan

Table 1-2 lists the State Condition requirements of this Plan and the sections in this Plan that fulfil them.

Table 1-2: Condition Requirements Addressed in this Plan

Approval Decision	Condition No.	Condition Requirement	Section in this Plan
MS 800	29.2 (i)	Ensure air quality meets appropriate standards for human health in the workplace.	Sections 5.1, 5.2, 5.3, 5.4, 5.5, 6.2, 6.3, 6.4, 7.1
MS 800	29.2 (ii)	Ensure air emissions from the Gas Treatment Plant operations do not pose a risk of Material or Serious Environmental Harm to the flora, vegetation communities, fauna, and subterranean fauna of Barrow Island.	Sections 5.1, 5.2, 5.3, 5.4, 6.2, 6.3, 6.4, 7.1
MS 800	29.3 (i)	The Plan shall include an ambient air monitoring program to ensure the objectives set in Condition 29.2 are met.	Sections 9.1, 9.2, 9.3, 9.4
MS 800	29.3 (ii)	The program shall include a list of chemicals to be monitored, the location of air quality sampling points and the frequency of air quality monitoring.	Section 9.3
MS 800	29.3 (iii)	The Plan shall include emission targets for these chemicals.	Section 4.1
MS 800	29.3 (iv)	The Plan shall include Performance Standards against which achievement of the objectives of this Condition [Condition 29] can be determined.	Sections 2.1, 2.2, 2.3, 8

Any matter specified in this Plan is relevant to the Gorgon Gas Development only if that matter relates to the specific activities or facilities associated with that particular development.

1.5 Other Legislation

Other legislative requirements include a range of secondary approvals such as works approvals, licences, and registrations under Part V of the *Environmental Protection Act 1986* (WA) (EP Act). Although every effort has been or will be made to ensure consistency, if there are any differences or ambiguity between the

management measures and commitments contained in this Plan and that of other related approval documentation and/or licences required, then the management measures and commitments contained in this Management Plan shall take precedence. This Plan is approved under the State EP Act and as such, takes precedence over inconsistent requirements in any secondary approval (e.g. a State works approval or licence).

Other regulatory plans that relate to this Plan are summarised in Table 1-3.

Table 1-3: Interfaces with other Regulatory Plans

Scope	Legislative Requirement	Regulatory Plan[1]
Regulates industrial emissions and discharges to the environment from the defined prescribed premise of the Gorgon LNG Project (three LNG trains). The operating licence prescribes emissions and discharges points, monitoring requirements, and limits for specific parameters. Regarding air emissions, it sets stack emission monitoring requirements, locations, frequency, and NATA accreditation requirements for: NOx, SOx, CO, VOC, PM, BTEX, H_2S, and Hg.	Part V of the EP Act; L9102/2017/1	Gorgon LNG Project Operating Licence L9102/2017/1 (Ref. 11)
Required to be submitted as part of the Works Approval application for the GTP, the Best Practice Pollution Control Design Report (BPPCDR): • Demonstrates that the proposed works adopt best practice pollution control measures to minimise emissions from the GTP • Sets out the base emission rates for major sources for the GTP and the design emission targets; and • Addresses normal operations, shut down, start up, and equipment failure conditions.	Condition 28 of MS 800 and MS 769	Best Practice Pollution Control Design Report (Ref. 12)
Defines and maps the pre-development baseline state of ecological elements including details of the methodology used to survey, collect, and collate information. Analyses data and information gaps associated with the baseline data for the identified ecological elements, and describes procedures to address these gaps. Defines the Terrestrial Disturbance Footprint (TDF) and reviews the results of qualitative ecological risk assessments.	Condition 6 of MS 800 and MS 769 Condition 5 of EPBC Reference: 2003/1294 and 2008/4178	Terrestrial and Subterranean Baseline State and Environmental Impact Report (TSBSEIR; Ref. 13)
Details the ecological monitoring program to detect any Serious or Material Environmental Harm to ecological elements outside the TDF.	Condition 16 of MS 800 Condition 12 of EPBC Reference: 2003/1294 and 2008/4178	Terrestrial and Subterranean Environment Monitoring Program (TSEMP; Ref. 14)
Details the management measures proposed to reduce adverse impacts from construction and operation of terrestrial facilities as far as practicable; and to ensure that construction and operations do not cause Serious or Material Environmental Harm outside the TDF.	Condition 7 of MS 800 Condition 6 of EPBC Reference: 2003/1294 and 2008/4178	Terrestrial and Subterranean Environment Protection Plan (TSEPP; Ref. 64)

[1]*Regulatory plans as amended or supplemented from time to time*

1.6 Scope

This Plan addresses the objectives listed in Section 1.4.2 by outlining the steps taken to manage emissions associated with the operation of the GTP.

The scope of this Plan covers the management of atmospheric pollutant and air toxics emissions associated with the commissioning, start-up, and operation of the GTP. Only atmospheric pollutant and air toxics emission sources from the GTP (as defined in Schedule 1 of MS 800) are included in the scope of this Plan.

The key atmospheric pollutants and air toxics considered in the scope of this Plan include:

- nitrogen dioxide (NO_2), as representative pollutant for nitrogen oxides (NOx), which is a generic term for the mono-nitrogen oxides, i.e. nitric oxide (NO) and NO_2
- airborne particulate matter (PM_{10}), which also includes particulate matter of size 2.5 microns and lower ($PM_{2.5}$)
- sulfur dioxide (SO_2), as representative pollutant for sulfur oxides (SOx), which include also sulfur monoxide (SO), sulfur trioxide (SO_3), and other combinations of sulfur and oxygen
- non-methane volatile organic compounds (NMVOCs), including aliphatic hydrocarbons (propane and longer straight chain hydrocarbons) and aromatic hydrocarbons such as benzene, toluene, ethylbenzene, and xylene, which are collectively known as BTEX
- carbon monoxide (CO)
- hydrogen sulfide (H_2S)
- ozone (O_3) – as a secondary pollutant, resulting from the interaction between NOx and volatile organic compounds (VOCs)
- mercury (Hg).

1.6.1 Out of Scope

Other atmospheric pollutant and air toxics emissions were also considered based on a review of the Commonwealth Department of Sustainability, Environment, Water, Population and Communities (SEWPaC; now known as the Department of Agriculture, Water and the Environment [DAWE]) National Pollutant Inventory (NPI) Guide (Ref. 15), associated NPI Substance List and Thresholds (Ref. 16), and emissions previously reported by other LNG Plant Operators (e.g. Woodside) on the NPI website. These emissions were subsequently excluded from the scope of this Plan as they are considered low risk due to their expected low emission rates during the commissioning, start-up and operation of the GTP. However, some of these atmospheric pollutant and air toxics emissions may require reporting via the NPI process as outlined in Table 1-4.

Table 1-4: Out of Scope Atmospheric Pollutants and Air Toxics

Atmospheric Pollutants and Air Toxics	Typical Emission Sources	Justification for Screening Out
Acetaldehyde	Natural gas-fired stationary gas	To be released in very low quantities and below the NPI Category 1 reporting threshold[1] of 10 tonnes per annum (Ref. 15; Ref. 16).

Atmospheric Pollutants and Air Toxics	Typical Emission Sources	Justification for Screening Out
	turbines and diesel engines	By comparison, Woodside Energy Ltd reported the following emissions to atmosphere on the NPI website: *Pluto Onshore Gas Treatment Plant* – • 2011–2012 – zero emissions (Ref. 17) • 2010–2011 – zero emissions (Ref. 18) *Karratha Onshore Gas Treatment Plant* – • 2011–2012 – zero emissions (Ref. 19) • 2010–2011 – zero emissions (Ref. 20).
Fluoride	Natural gas-fired stationary gas turbines and diesel engines	To be released in very low quantities and below the NPI Category 1 reporting threshold[1] of 10 tonnes per annum (Ref. 15; Ref. 16). However, requires reporting based on NPI Category 2a and 2b reporting thresholds[2, 3] (Ref. 15; Ref. 16). By comparison, Woodside Energy Ltd reported the following emissions to atmosphere on the NPI website: *Pluto Onshore Gas Treatment Plant* – • 2011–2012 – zero emissions (Ref. 17) • 2010–2011 – zero emissions (Ref. 18) *Karratha Onshore Gas Treatment Plant* – • 2011–2012 – zero emissions (Ref. 19) • 2010–2011 – zero emissions (Ref. 20).
Formaldehyde	Natural gas-fired stationary gas turbines and diesel engines	To be released in very low quantities and below the NPI Category 1 reporting threshold[1] of 10 tonnes per annum (Ref. 15; Ref. 16) only. By comparison, Woodside Energy Ltd reported the following emissions to atmosphere on the NPI website: *Pluto Onshore Gas Treatment Plant* – • 2011–2012 – zero emissions (Ref. 17) • 2010–2011 – zero emissions (Ref. 18) *Karratha Onshore Gas Treatment Plant* – • 2011–2012 – zero emissions (Ref. 19) • 2010–2011 – zero emissions (Ref. 20).
Heavy metals[4, 5]	Natural gas-fired stationary gas turbines, flares, and diesel engines	To be released in very low quantities and below the NPI Category 1 reporting threshold[1] of 10 tonnes per annum (Ref. 15; Ref. 16). However, requires reporting based on NPI Category 2b reporting threshold[3] (Ref. 15; Ref. 16). By comparison, Woodside Energy Ltd reported the following emissions to atmosphere on the NPI website: *Pluto Onshore Gas Treatment Plant* – • 2011–2012 – 25.8 kg (Ref. 17) • 2010–2011 –0.45 kg (Ref. 18). *Karratha Onshore Gas Treatment Plant* – • 2011–2012 –153.7 kg (Ref. 19) • 2010–2011 –162.6 kg (Ref. 20).
Polycyclic Aromatic Hydrocarbons (PAHs)	Natural gas-fired stationary gas turbines, flares, and diesel engines	To be released in very low quantities; however, requires reporting based on NPI Category 2a and 2b reporting thresholds[4, 5] (Ref. 15; Ref. 16). By comparison, Woodside Energy Ltd reported the following emissions to atmosphere on the NPI website:

Atmospheric Pollutants and Air Toxics	Typical Emission Sources	Justification for Screening Out
		Pluto Onshore Gas Treatment Plant – • 2011–2012 – 1.9 kg (Ref. 17) • 2010–2011 – 1.2 × 10^{-5} kg (Ref. 18) *Karratha Onshore Gas Treatment Plant –* • 2011–2012 – 0.16 kg (Ref. 19) • 2010–2011 – 0.15 kg (Ref. 20).
Polychlorinated Dioxins and Furans	Natural gas-fired stationary gas turbines and diesel engines	To be released in very low quantities; however, requires reporting based on NPI Category 2b reporting thresholds[5] (Ref. 15; Ref. 16). By comparison, Woodside Energy Ltd reported the following emissions to atmosphere on the NPI website: *Pluto Onshore Gas Treatment Plant –* • 2011–2012 – 1.1 × 10^{-8} kg (Ref. 17) • 2010–2011 – zero emissions (Ref. 18) *Karratha Onshore Gas Treatment Plant –* • 2011–2012 – 3.8 × 10^{-8} kg (Ref. 19) • 2010–2011 – 4.3 × 10^{-8} kg (Ref. 20).

Note:

1. *NPI Reporting Threshold – Category 1 – contains a broad range of substances that are typically used for production. Most NPI substances fall into this category. The threshold for this category is the 'use' of 10 tonnes or more per year of a Category 1 substance. For NPI purposes 'use' is defined as the handling, manufacture, import, processing, coincidental production, or other use of a substance (Ref. 15; Ref. 16).*
2. *NPI Reporting Threshold – Category 2a includes:*
   - *burning 400 tonnes or more of fuel and/or waste in the reporting year, or*
   - *burning 1 tonne or more of fuel and/or waste in an hour at any time during the reporting year (Ref. 15; Ref. 16).*
3. *NPI Reporting Threshold – Category 2b includes:*
   - *burning 2000 tonnes or more of fuel and/or waste in the reporting year, or*
   - *consuming 60 000 MW hours or more of electrical energy for other than lighting or motive purposes in the reporting year, or*
   - *having maximum potential power consumption of 20 MW or more for other than lighting or motive purposes in the reporting year (Ref. 15; Ref. 16).*
4. *Heavy metals include arsenic, beryllium, cadmium, chromium, copper, lead, Hg, nickel and zinc compounds.*
5. *NPI Reporting Threshold – Category 1b – contains only Hg and compounds. Due to the high toxicity of Hg and its exposure potential, it has a lower threshold than Category 1 substances. The threshold for Hg and compounds includes the use of 5 kg or more in the reporting year (Ref. 15; Ref. 16).*

Note: The Best Practice Pollution Control Design Report (Ref. 12) specifically outlines the best practice pollution control equipment selected to control the major emission sources of atmospheric pollutants and air toxics at the GTP. This report also lists the associated base emission rates and design emission targets applicable to these major emission sources during the operations phase of the GTP. The base emission rates were used as inputs into air quality modelling studies (the results of which are discussed in Sections 5 and 6) that supported the development of the ambient air quality monitoring program (as outlined in Section 9 of this Plan).

The management of greenhouse gas (GHG) emissions, including carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4), is excluded from the scope of this Plan. The Greenhouse Gas Abatement Program (Ref. 21) provides specific information related to the management of GHG emissions associated with the operation of the GTP.

2 Relevant Regulatory Requirements

2.1 National Ambient Air Quality Standards

The National Ambient Air Quality Guidelines are specified by the NEPC. These include the following:

- National Environment Protection (Ambient Air Quality) Measure (NEPM) (Ref. 22)
- National Environment Protection (Air Toxics) Measure (Ref. 23).

The following sections outline the specific ambient air quality standards considered relevant to the commissioning, start-up, and operation of the GTP in the context of this Plan.

2.1.1 NEPM (Ambient Air Quality) Standards and Goals

The National Environment Protection (Ambient Air Quality) Measure (NEPM; Ref. 22) provides legally binding standards for levels of atmospheric pollutants in the ambient environment, below which ambient air quality is acceptable (e.g. allowing for the adequate protection of human health and wellbeing). The key target species of atmospheric pollutants relevant to the context of this Plan include NO_2 (as representative of NOx), PM_{10} (inclusive of $PM_{2.5}$), SO_2 (as representative for SOx), CO, and O_3 (as a secondary pollutant). The associated NEPM (Ambient Air Quality) standards and goals for these key atmospheric pollutants are listed in Table 2-1.

These standards and goals were used to assess potential impacts to ambient air quality based on the results of the air quality modelling studies, and shall be used to assess any potential future impacts to ambient air quality on Barrow Island based on the results from the ambient air quality monitoring program outlined in Section 9.

Appendix A describes the potential generic impacts on human health and the environment from each key atmospheric pollutant considered in the scope of this Plan.

Table 2-1: NEPM (Ambient Air Quality) Standards and Goals

Atmospheric Pollutants	Averaging Period	Maximum (Ambient) Concentrations		Goal (Maximum Allowable Exceedances)
		ppm	µg/m³	
Nitrogen dioxide (NO_2)	1 hour 1 year	0.12 0.03	246 62	1 day a year none
Sulfur dioxide (SO_2)	1 hour 1 day 1 year	0.20 0.08 0.02	571 229 57	1 day a year 1 day a year none
Airborne particulate matter as PM_{10}	1 day	--	50	5 days a year
Carbon monoxide (CO)	8 hours	9.0	--	1 day a year
Photochemical oxidants (as ozone – O_3)	1 hour 4 hours	0.10 0.08	214 171	1 day a year 1 day a year

Source: Ref. 22

2.1.2 NEPM (Air Toxics) Monitoring Investigation Levels

The National Environment Protection (Air Toxics) Measure (Ref. 23) sets monitoring investigation levels for air toxics, for which any exceedance requires some form of evaluation to determine the circumstances that led to the exceedance, including the likely sources of the air toxics and the influence of natural factors.

Air toxics are a diverse range of pollutants present in ambient air in relatively low concentrations, which have characteristics such as toxicity or persistence that make them a hazard to human, plant, or animal health. Air toxics include volatile and semi-volatile organic compounds, heavy metals, and others. The air toxics relevant to this Plan include benzene, toluene, and xylene. Table 2-2 lists the monitoring investigation levels for these air toxics.

These monitoring investigation levels are to be taken into account when assessing the likelihood of potential future impacts to ambient air quality on Barrow Island by comparing against the results from the ambient air quality monitoring program outlined in Section 9.

Appendix A describes the potential generic impacts on human health and the environment from the key air toxics considered in the scope of this Plan.

Table 2-2: NEPM (Air Toxics) Monitoring Investigation Levels

Air Toxics	Averaging Period	Monitoring Investigation Levels[1]	
		ppm[2]	µg/m^3[3]
Benzene	1 year	0.003	9.6
Toluene	1 day 1 year	1.0 0.1	3780 380
Xylene (as a total of ortho-, meta- and para-isomers)	1 day 1 year	0.25 0.2	1085 870

Source: Ref. 23

Notes:

1. *For these measures, the annual average concentrations are the arithmetic mean concentrations of 24-hour monitoring results (from midnight to midnight).*
2. *Monitoring Investigation Levels reported in ppm are by volume.*
3. *Monitoring Investigation Levels reported in µg/m^3 assume a temperature of 25 °C and a pressure of 101.3 kPa.*

When the National Environment Protection (Air Toxics) Measure was initially scoped, the NEPC agreed that a phased approach would be adopted so that hazardous pollutants that were not included in the original standard could be incorporated at a later date. The NEPC agreed to establish a working group to develop a methodology to prioritise additional hazardous pollutants to be considered for inclusion (initially selected from the NPI list of substances). A detailed list of the prioritised pollutants is provided in the NEPC Air Toxics Tier 2 Prioritisation Methodology Report (Ref. 24). Any future updates to the National Environment Protection (Air Toxics) Measure are to be reviewed by CAPL and considered for use on the Gorgon Gas Development.

2.2 National Occupational Health Exposure Standards

The National Occupational Health Exposure Standards are specified by Safe Work Australia (SWA) within the Hazardous Substances Information System (HSIS) Exposure Standards (Ref. 25).

Table 2-3 lists the national occupational health exposure standards considered relevant to the commissioning, start-up, and operation of the GTP in the context of this Plan. These exposure standards represent airborne concentrations of particular substances in a worker's breathing zone, exposure to which, according to current knowledge, should not cause adverse health effects nor cause undue discomfort to nearly all workers. As with the NEPM standards, these occupational health exposure standards were taken into account when assessing potential impacts to human health based on the results of the air quality modelling studies, and are to be used to assess any potential future impacts to human health based on the results from the ambient air quality monitoring program outlined in Section 9.

Appendix A describes the potential generic impacts on human health from the key atmospheric pollutants and air toxics considered in the scope of this Plan.

Table 2-3: National Occupational Health Exposure Standards

Substance	Time-weighted Average (TWA)[1]		Short-term Exposure Limit (STEL)[2]	
	ppm[3]	µg/m^3	ppm[3]	µg/m^3
Nitrogen dioxide (NO_2)	3	5600	5	9400
Sulfur dioxide (SO_2)	2	5200	5	13 000
Ozone (O_3)	0.1[4]	200[4]	N/A[4]	N/A[4]
Hydrogen sulfide (H_2S)	10[5]	14 000[5]	15[5]	21 000[5]
Benzene (C_6H_6)	1	3200	--	--
Toluene (C_7H_8)	100	377 000	150	565 000
Ethylbenzene (C_8H_{10})	100	434 000	125	543 000
Xylene (o-, m- and p-isomers)	80	350 000	150	655 000

Source: Ref. 25

Notes:

1. *The time-weighted average (TWA) concentration is measured over a normal eight-hour work day and a 40-hour work week, and is the concentration of an atmospheric contaminant to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.*
2. *A short-term exposure limit (STEL) is the maximum concentration to which workers can be exposed for a short period of time (15 minutes) for only four times throughout the day, with at least one hour between exposures.*
3. *National Occupational Health Exposure Standards reported in ppm are by volume.*
4. *For some rapidly acting substances and irritants, the averaging of the airborne concentration over an eight-hour period is inappropriate. These substances may induce acute effects after relatively brief exposure to high concentrations and so the exposure standard for these substances represents a maximum or peak concentration to which workers may be exposed. Although it is recognised that there are analytical limitations to the measurement of some substances, compliance with these 'peak limitation' exposure standards should be determined over the shortest analytically practicable period of time, but under no circumstances should a single determination exceed 15 minutes.*
5. *Note that the occupational health exposure levels for H_2S used internally by CAPL are a TWA of 5 ppm (or 7000 µg/m^3) and a STEL of 15 ppm (or 21 000 µg/m^3) (Ref. 26). Conversions from ppm to µg/m^3 assume a temperature of 25 °C and a pressure of 101.3 kPa.*

2.3 Other Regulatory Considerations

The EPA's air quality protection objective, as noted in the EPA's Environmental Assessment Guideline for Environmental Factors and Objectives (Ref. 27), is to ensure that, by meeting statutory requirements and acceptable standards, emissions do not adversely affect environmental values or the health, welfare, and amenity of people and land uses.

The DEC's (now DWER) Ambient Air Modelling Guidance Notes (Ref. 28) requires that the proponent is responsible for identifying and quantifying all emissions to atmosphere with a potential to have a non-trivial impact on the environment; this includes impacts on human health and wellbeing, odour, nuisance, amenity, vegetation (natural and agricultural), and fauna (natural and agricultural).

These Guidance Notes (Ref. 28) also require that air quality modelling, using an acceptable and verified DWER model, be undertaken for those suspected non-trivial impact emissions. The modelling predictions, in terms of ambient air pollutant concentrations and/or rates of deposition, used to assess compliance with the relevant standards/goals and guidelines are mentioned in the Ambient Air Quality Guidelines (Ref. 29).

Specifically, the Ambient Air Quality Guidelines (Ref. 29) state that the EPA and DEC (now DWER) have adopted the NEPM standards outlined in Sections 2.1.1 and 2.1.2, and, in the absence of an appropriate NEPM standard for a particular pollutant, recommend the use of the World Health Organization (WHO) Guidelines for Air Quality for Europe (Ref. 30). Furthermore, in the absence of both a suitable NEPM standard and WHO guideline, the EPA and DWER adopt criteria from other jurisdictions, if determined to be applicable to the WA context.

On this basis, CAPL has used additional criteria to assess if the impacts from the modelled ambient air pollutants and air toxics associated with the operation of the GTP are considered as 'non-trivial', and therefore, could impact human health or cause 'Material or Serious Environmental Harm' to the flora, vegetation communities, terrestrial fauna, and subterranean fauna of Barrow Island. The additional criteria used when assessing 'non-trivial' impacts based on the modelled results are discussed in the sections below.

2.3.1 Assessment of Non-occupational Health Exposure Effects

The potential for low-level H_2S and BTEX concentrations to be present in the ambient air environment has necessitated the assessment of general, non-occupational type health exposure effects (e.g. impacts to human health from exposure outside working environments) to the commissioning, start-up, and operations workforce on Barrow Island. Such exposures potentially occur following prolonged periods of acid gas venting, which are most likely to occur:

- during the GTP commissioning and start-up phase
- during occasional periods of unavailability of the GTP CO_2 compression and injection systems during the operations phase.

The criteria used when assessing these exposure effects are outlined in the following sections.

2.3.1.1 Additional Impact Assessment Criteria for Air Toxics

Additional impact assessment criteria for air toxics have been sourced from the New South Wales (NSW) DEC's Approved Methods for Modelling and Assessment of Air Pollutants in New South Wales (Ref. 31). CAPL's use of this guidance document is based on advice received from the Industry Regulation Branch, Pilbara Region, WA (Ref. 32), which is that the air toxics criteria listed in Table 2-4 are to be used by DWER during the Works Approval process when assessing the environmental acceptability of the impacts from the GTP on ambient air quality as demonstrated through air quality modelling.

As such, these criteria have been taken into account when assessing general, non-occupational type health exposure effects on the workforce on Barrow Island based on the results of the air quality modelling studies. The air toxics relevant to this Plan include benzene, toluene, ethylbenzene, and xylene (collectively known as BTEX).

Table 2-4: Impact Assessment Criteria for Air Toxics

Pollutant	Averaging Period	Concentration[1]	
		ppm	µg/m^3
Benzene[2]	1 hour	0.009	29
Toluene[3]	1 hour	0.09	360
Ethylbenzene[2]	1 hour	1.8	8000
Xylene[3]	1 hour	0.04	190

Source: Ref. 31

Notes:

1. *Gas volumes are expressed at 25 °C and at an absolute pressure of 1 atmosphere (101.325 kPa).*
2. *Impact assessment criteria to be applied at and beyond the property boundary.*
3. *Impact assessment criteria to be applied at the nearest existing or likely future off-site sensitive receptor.*

2.3.1.2 Additional Impact Assessment Criteria for Odorous Air Pollutants

In addition, the Approved Methods for Modelling and Assessment of Air Pollutants in New South Wales (Ref. 31) recommend that impact assessment criteria for odorous air pollutants, such as H_2S, be used as a function of population density. The variation in population numbers on Barrow Island during the commissioning, start-up, and operations phases translates into the following impact assessment criteria for non-occupational exposure to H_2S on Barrow Island:

- For the commissioning and start-up phase (population of affected community at Butler Park [formerly the Construction Village] and Chevron Camp more than 2000): 1.38 µg/m^3 (equivalent to 1.0 parts per billion [ppb])
- For the operations phase (population of affected community at Butler Park and Chevron Camp fewer than 500): 2.07 µg/m^3 (equivalent to 1.5 ppb).

The above H_2S impact assessment criteria are based on a nose-response-time average, 99th percentile. These criteria were taken into account when assessing general, non-occupational type health exposure effects from H_2S on the workforce on Barrow Island based on the results of the air quality modelling studies.

Furthermore, additional literature research undertaken by CAPL into other exposure criteria used for H_2S found the following in the WHO Air Quality Guidelines for Europe (Ref. 30):

- concentrations that should not be exceeded in order to avoid complaints from the exposed population (based on sensory effects or annoyance reactions):
  - detection threshold of 0.2 to 2.0 µg/m^3
  - recognition threshold of 0.6 to 6.0 µg/m^3
  - 30-minute average guideline value of 7 µg/m^3
- 24-hour average guideline value of 150 µg/m^3 – based on effects other than cancer or odour/annoyance

- lowest observed adverse effect level (LOAEL) for humans is reported as 15 mg/m^3, when eye irritation occurs.

It is important to note that the NSW DEC criteria used by CAPL when assessing general, non-occupational type health exposure effects from H_2S on the workforce on Barrow Island based on the results of the air quality modelling studies, are considered more stringent that the 30-minute, 24-hour, and LOAEL WHO criteria values listed above.

2.3.2 Assessment of Other Potential Environmental Impacts

As noted in Section 2.3, the DEC's Guidance Note (Ref. 28) requires that air quality modelling be undertaken to assess potential impacts from 'non-trivial' emissions. On this basis, CAPL used the results of the air quality modelling studies to assess potential impacts to the environment from acid deposition using the criteria outlined in Sections 2.3.2.1 and 2.3.2.2.

Acid deposition ('acid rain') occurs when SO_2 and NOx react with water, oxygen, and other oxidants in the atmosphere to form acidic compounds. These acidic compounds precipitate in rain, snow and fog, or, in dry form, as gases and particles. The SO_2 and NOx gases and their PM derivatives may contribute to air quality impacts, e.g. by the acidification of lakes and streams, damage to forest ecosystems, and acceleration of the decay of building materials (Ref. 33).

For Barrow Island and the Pilbara Region, dry deposition processes are expected to dominate because of the predominantly dry climate of the region.

Acid deposition guidelines have been sourced from the WHO Air Quality Guidelines for Europe (Ref. 30). The WHO guidelines list critical levels and critical loads for depositions for the assessment of nitrogen and sulfur, and 'acid equivalent' impacts on natural ecosystems.

2.3.2.1 Critical Levels for Deposition

Critical levels relate to direct effects on plant physiology, growth, and vitality, and are expressed as atmospheric concentrations or cumulative exposures over a given averaging time. Typically, critical levels are based on effects observed over periods from one day to several years.

The WHO guideline value for critical levels of nitrogen deposition (which includes mainly nitric oxide [NO]), nitrogen dioxide [NO_2], and ammonia [NH_3]) and sulfur deposition (expressed as SO_2) are:

- 30 µg/m^3 for NOx (NO and NO_2) and 8 µg/m^3 for NH_3 expressed as an annual mean concentration
- 10 to 30 µg/m^3 for SO_2 expressed as an annual and winter mean concentration (the range depending on the type of vegetation).

2.3.2.2 Critical Loads for Deposition

Critical loads relate to effects on ecosystem structure and functioning, and are expressed as annual depositions of mass or acidity. In the case of sulfur and nitrogen compounds, critical levels can be directly related to critical loads when the deposition velocity for a given vegetation type is known.

Critical loads also provide the long-term deposition, below which significant harmful effects on specified sensitive elements of the environment are not expected to occur to the best current knowledge (Ref. 30).

The critical loads for deposition of nitrogen (N) are between five and 35 kg N/ha/year, depending on the type of soil and ecosystem. The ecosystem example used for nitrogen in this Plan is 15 to 20 kg/ha/year for lowland dry heathland as elemental nitrogen.

The critical load for deposition of acid equivalents is 250 to 1500 eq/ha/year (units are 'acid equivalents' per hectare per year), depending on the type of soil and ecosystem. The ecosystem example used for comparison with modelling results in this Plan is 250 to 500 eq/ha/year, appropriate for fluvial and marine sediment terrestrial environments (Ref. 30). Deposition of acid equivalents can be converted to deposition of SO_2 (taking into account the moles of charge of deposition, the ionic charge of sulfur, and the molecular weights of sulfur and SO_2) to give a critical load for SO_2 deposition in the range of 8 to 16 kg/ha/year.

As the feed gas composition processed through the GTP is expected to contain very low quantities of sulfur-containing compounds, emissions of SO_2 combined with very low background concentrations are assumed to be insignificant relative to the critical levels and critical loads, and thus have not been used in the air quality modelling and environmental harm assessment in this Plan.

Effects on terrestrial and marine flora and fauna from air pollutants and air toxics emitted from the GTP are discussed in detail in Sections 5 and 6.

2.3.3 Assessment of Potential Mercury Impacts

The relevant regulatory standards and requirements associated with Hg are summarised in the following tables. Note: There are no relevant assessment criteria associated with Hg deposition.

Table 2-5: Residential Exposure Impact Assessment Criteria for Mercury

Pollutant	Averaging Period	Concentration	
		ppb	µg/m^3
Hg – Inorganic[1]	1 hour	--	1.8
Hg – Elemental[2]	Annual	--	0.2

Notes:

1. *Source: Ref. 31.*
2. *Source: Ref. 34. Tolerable concentration for long-term inhalation exposure to elemental Hg vapour.*

Table 2-6: National Occupational Health Exposure Standards

Substance	TWA[1]	
	ppm[2]	µg/m^3[3]
Hg – Elemental	0.003	25

Source: Ref. 25

Notes:

1. *The TWA concentration is measured over a normal eight-hour work day and a 40-hour work week, and is the concentration of an atmospheric contaminant to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.*
2. *National Occupational Health Exposure Standards reported in ppm are by volume.*
3. *The occupational health exposure level for Hg used internally by CAPL is a TWA of 15 µg/m^3, which applies only for entry into medical surveillance programs (Ref. 35).*

3 Facility Description

This Plan applies to the Terrestrial Facilities of the Gorgon Gas Development, which are shown in Figure 3-1. The Gorgon Gas Development Terrestrial Facilities are defined in Condition 6.3 of MS 800 and Condition 5.2 of EPBC Reference: 2003/1294 and 2008/4178 as the:

- Gas Treatment Plant
- Carbon Dioxide Injection system
- Associated Terrestrial Infrastructure forming part of the proposal
- Areas impacted for seismic data acquisition
- Onshore Feed Gas Pipeline System and terrestrial component of the shore crossing.

Terrestrial Facilities also include those defined in Schedule 1 of MS 965 (the Additional Support Area).

The scope of this Plan covers the management of atmospheric pollutant and air toxics emissions associated with the operation of the GTP. Only atmospheric pollutant and air toxics emission sources from the GTP (as defined in Schedule 1 of MS 800) are included in the scope of this Plan.

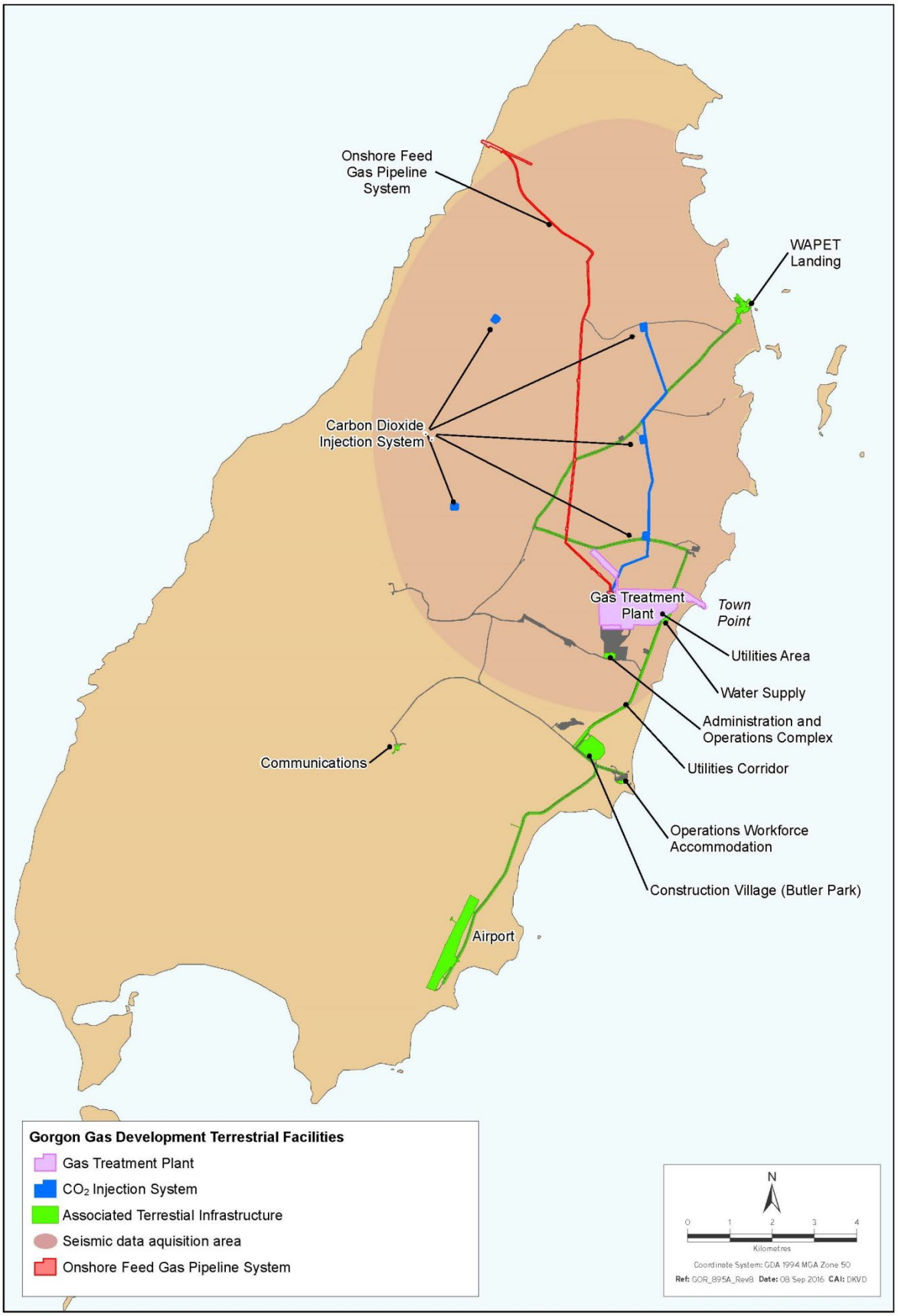


Figure 3-1: Gorgon Gas Development Terrestrial Facilities on Barrow Island

3.1 Overview of Production Facilities

The Gorgon Gas Development concept is a three-train (3 × 5 MTPA) GTP, with the GTP located near Town Point on the east coast of Barrow Island (Figure 3-1). The offshore supply configuration comprises two subsea developments within the Gorgon and Jansz fields, tied back via separate production pipelines to the GTP. The produced fluids will be transported from each gas field to the GTP through separate large-diameter, high-pressure multiphase (gas, condensate, and aqueous phase) pipelines.

At Barrow Island, the hydrocarbon liquid (condensate) and water phases will be separated from the gas stream in inlet separation facilities. The saturated gas will form the feedstock for the LNG production and export facility. The GTP will comprise the following key processes:

- inlet processing, monoethylene glycol (MEG) regeneration, and condensate stabilisation
- acid gas removal and CO_2 compression and injection
- dehydration
- mercury removal
- liquefaction, fractionation, and refrigerant make-up
- nitrogen removal and end flash gas compression
- LNG and condensate storage and offloading
- domestic gas (DomGas) unit and export pipeline.

The GTP has an anticipated average stream day capacity of up to 47 520 tonnes per day of LNG production from three LNG trains run down to the LNG Storage Tanks. This equates to a nominal annual average LNG production of 15.6 MTPA Freight On Board (FOB) based on 340.4 stream days per year.

Figure 3-2 shows a block flow diagram of these processes within the GTP. These processes are further discussed in Section 3.2.

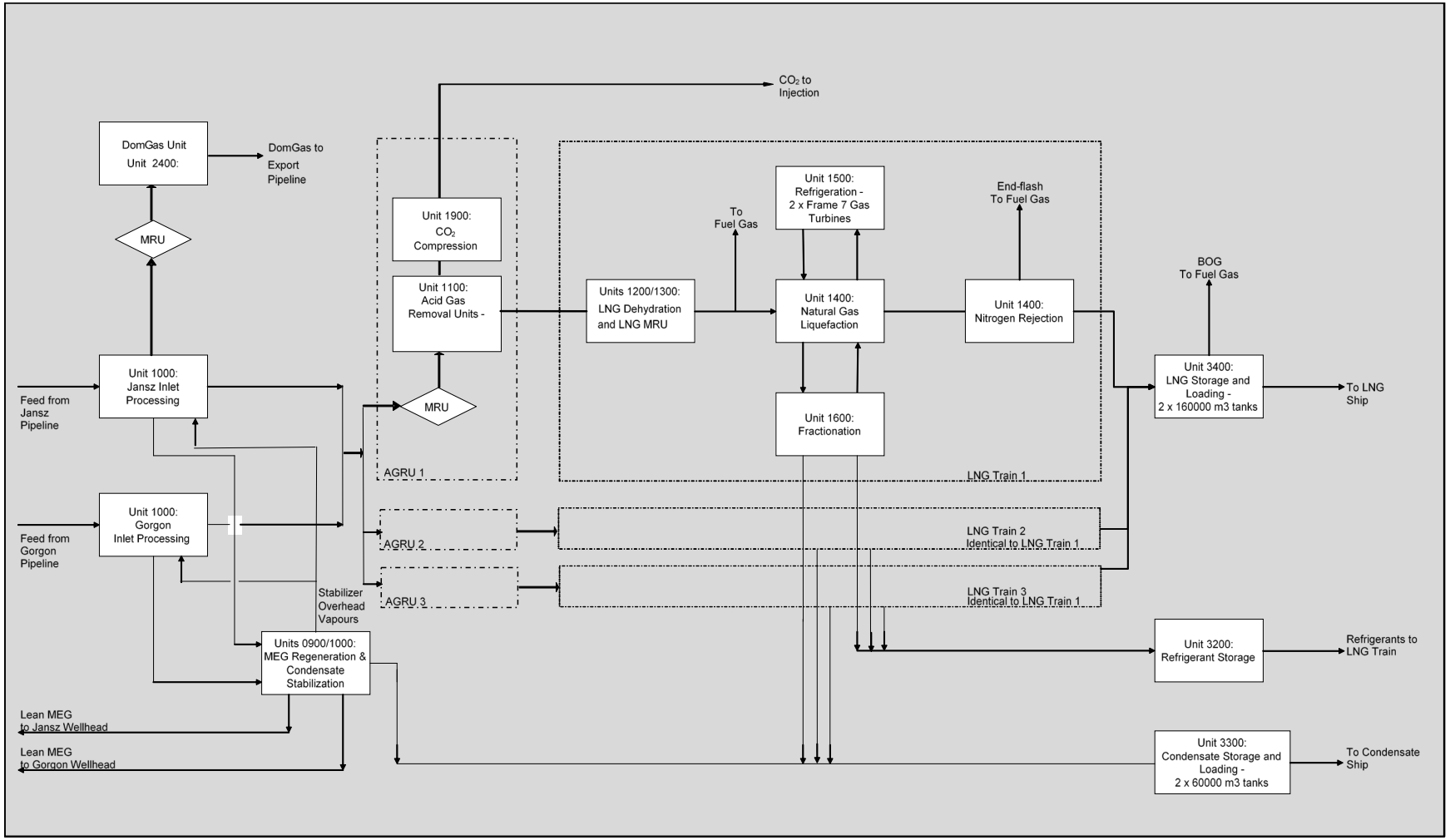


Figure 3-2: Gorgon Gas Development GTP Block Flow Diagram (Normal Operations)

3.2 GTP Processing Facilities

3.2.1 Inlet Processing, MEG Regeneration, and Condensate Stabilisation

The Gorgon and Jansz feed gas arrives at dedicated Gorgon and Jansz inlet processing facilities (slug catchers) that are designed to segregate the incoming fluids into three separate phases (gas, condensate, and aqueous) and to provide steady flow rates to the downstream units. The reduced-pressure gas phase is combined and sent to the AGRUs. A side stream of gas downstream of the Jansz slug catcher is sent to the DomGas Plant for processing and export.

The aqueous phase is sent to the MEG Regeneration unit, designed to regenerate the rich (water-saturated) MEG—MEG is used to inhibit hydrate formation in the pipelines—by removing water and salts from a slipstream of the reconcentrated MEG to meet lean MEG specifications. Recovered lean MEG is sent back to the Gorgon and Jansz production wellheads via dedicated MEG utility pipelines. MEG flash gas is compressed and directed to the Condensate Stabilisation units, or either vented or flared in the Wet Gas Flare when this system is not available. The condensate stream is sent to Condensate Stabilisation, where further stripping of the light hydrocarbon components occurs to produce a stabilised condensate stream, which is combined with the condensate from the LNG Train Fractionation Unit prior to storage and export. Vapours (including those received from the MEG gas compressor) are directed back to the inlet facilities and added to the gas stream routed to the AGRU trains.

3.2.2 Acid Gas Removal and Carbon Dioxide Compression and Injection

The comingled Gorgon and Jansz gas phase streams from the slug catchers and the condensate stabilisation unit are routed to the AGRU for CO_2 and H_2S (collectively termed ‘acid gas’) removal from the natural gas using a proprietary activated Methyl Di-ethanol Amine (a-MDEA) technology. Acid gas must be removed from the natural gas to prevent it from freezing at low temperatures in the cryogenic sections of the GTP and to meet the LNG product CO_2 and sulfur specifications.

Each AGRU is designed to process 33% of the combined Gorgon and Jansz gas stream, and comprises three subsystems:

- an MRU to remove Hg from the acid gas stream prior to injection via the CO_2 Injection System or venting to the atmosphere
- an Absorber System to remove CO_2 and H_2S from the natural gas by absorption in an a-MDEA solvent
- a Regenerator System to regenerate the a-MDEA solvent for re-use by separating it from the acid gas components, removed from the natural gas in the Absorption System (see Figure 3-3).

The removed acid gas, containing 99.7 mole percent of CO_2 and minor residual amounts of volatile organic compounds (VOCs) and H_2S, is compressed in the CO_2 Injection System and injected into the subsurface Dupuy Formation, or vented if a compression and injection system failure occurs.

The CO_2 Injection System comprises 2 × 50% CO_2 Injection units (A and B) dedicated to each AGRU (see Figure 3-3).

Failure of any critical equipment inside each injection unit is likely to result in the immediate shutdown of that unit and local acid gas venting. The second CO_2

injection unit is expected to operate normally during this time. Maintenance on the critical equipment in the shutdown unit is not expected to adversely affect the operation of the second unit; i.e. it is expected that equipment failure in one unit will result in acid gas venting from that unit only, allowing 50% of the acid gas stream processed through the affected AGRU train to continue to be injected.

The CO_2 injection facilities, downstream of the CO_2 injection units, are not part of the GTP, but are described here for information.

The compressed acid gas is injected via nine CO_2 injection wells, drilled directionally from three CO_2 drill centres. A CO_2 pipeline runs from the CO_2 compressors on the north side of the GTP to these drill centres.

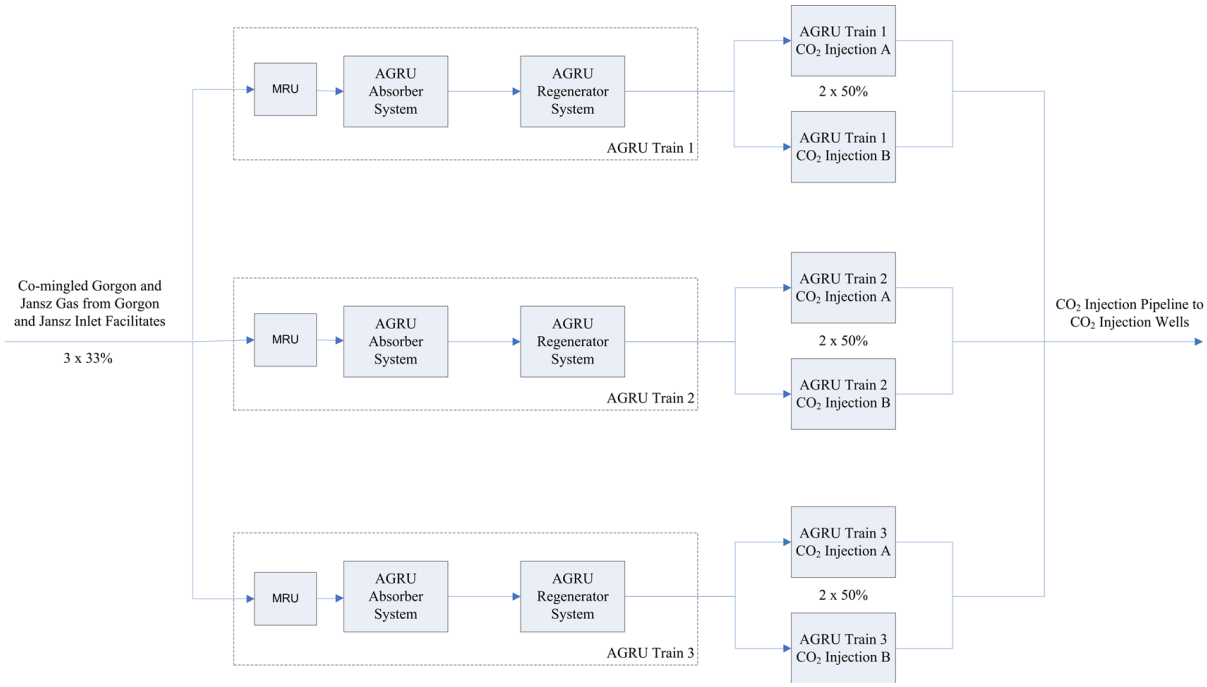


Figure 3-3: Acid Gas Removal and CO_2 Injection System Block Flow Diagram

3.2.3 Dehydration and Mercury Removal in LNG Trains 1–3

The purpose of the Dehydration Unit in each LNG train is to remove water from the treated hydrocarbon gas leaving the AGRUs. The treated gas is then dried in a molecular sieve to remove the final traces of water and to prevent hydrate formation in the Liquefaction Unit, which could cause blockages of lines and equipment.

The purpose of the MRU in each LNG train is to remove trace quantities of Hg present in the feed gas to the Liquefaction Unit to prevent corrosion of the heat exchanger tubes in the Main Cryogenic Heat Exchanger (MCHE).

3.2.4 Liquefaction, Fractionation, and Refrigerant Make-up in LNG Trains 1–3

Heavy hydrocarbons, which can freeze in the LNG, need to be removed before the dry treated gas from the MRUs can be liquefied. The dry treated gas is pre-cooled and fed to the Scrub Column. The Scrub Column removes heavy hydrocarbons and aromatics to comply with LNG product specifications and to prevent freezing at cryogenic temperatures in the MCHE, and recovers ethane

and propane from the natural gas allowing sufficient refrigerant make-up to be produced in the Fractionation Unit. The cooling medium is ambient air.

Liquefaction is the main component of the LNG train; it chills the natural gas to a temperature at which LNG can be produced using large gas turbines and a series of cryogenic heat exchangers. The liquefaction process is the Air Products and Chemicals Incorporated (APCI) Split–MR™ Propane Pre-Cooled Mixed Refrigerant (MR) Process (see Figure 3-4). Each LNG train has refrigeration compressors driven by Frame 7 Process Gas Turbines (GTs).

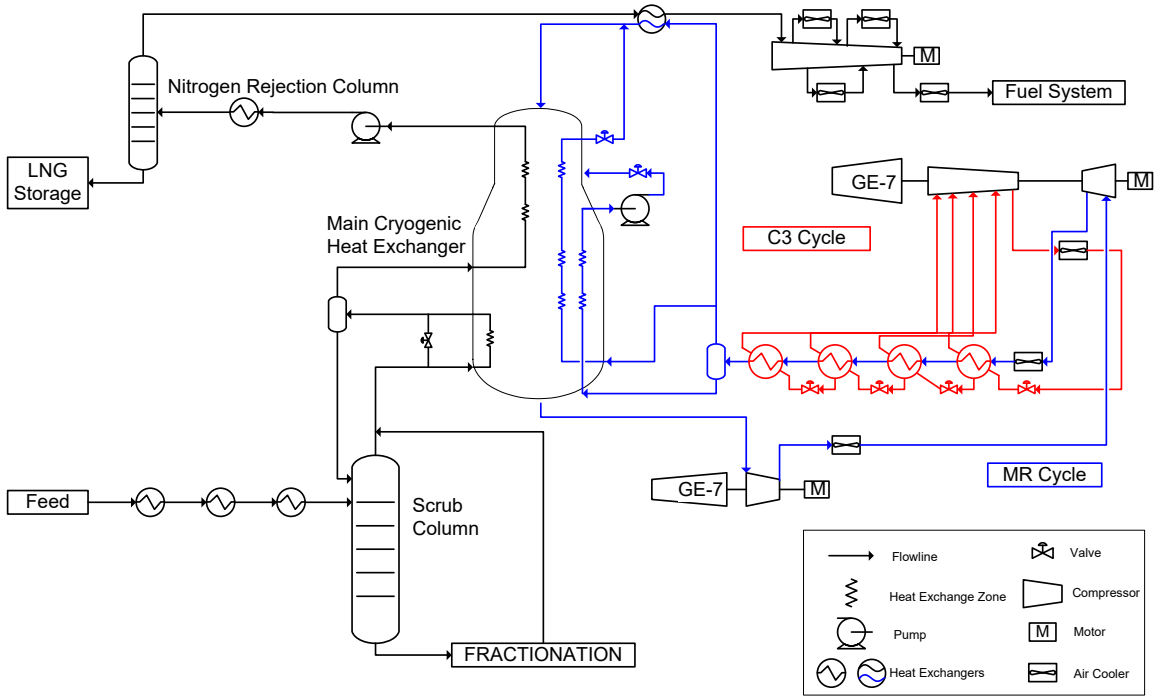


Figure 3-4: APCI 5 MTPA Refrigeration Cycle

Legend:

GE-7	*Frame 7 GTs, driving the Refrigeration Compressors*
C3 Cycle	*Propane Refrigerant Cycle*
MR Cycle	*Mixed Refrigerant Cycle*
M	*Refrigerant Compressor Helper Motor*

3.2.5 Nitrogen Removal and End Flash Gas Compression in LNG Trains 1–3

LNG is further cooled in the Nitrogen Column Reboiler and subsequently flashed off in the top of the Nitrogen Rejection Column. The LNG product separates in the Nitrogen Rejection Column bottom and is pumped to the LNG Storage Tanks. End flash gas is routed to a multistage End Flash Gas Compressor, which compresses it to the pressure required for the high-pressure fuel gas system.

3.2.6 LNG and Condensate Storage and Offloading

The LNG Storage and Loading unit provides storage and loading facilities to allow continuous production of LNG at the designed production rates and to enable intermittent exports by LNG carriers. The two LNG Storage tanks are full containment tanks with a net capacity of 180 000 m^3 each. Boil-off gas (BOG) from the LNG Storage Tanks is collected, compressed, and returned to the high-pressure fuel gas system inside the LNG trains.

The LNG Jetty, located approximately 4 km offshore from the GTP at Town Point, has two LNG Carrier Berths, each equipped with four loading arms; i.e. two liquid loading arms, one hybrid (liquid and vapour), and one vapour return arm. The BOG generated during LNG loading of the LNG carriers is routed back down the jetty via the vapour return arm and the vapour return line, and compressed and recycled as feed gas to the Dehydration and MRUs inside the LNG trains. Two BOG (marine) flares safely dispose of BOG in the event of BOG compressor failure and warm LNG carrier de-inerting.

The Condensate Storage and Loading Unit provides storage and loading facilities to allow continuous production of condensate at the design capacity of the GTP and to enable intermittent exports by condensate tankers. The four condensate storage tanks will be emptied by periodic loading of condensate tankers through a load-out line that runs along the LNG Jetty and terminates at the loading platform at two 50% condensate loading arms.

3.2.7 Domestic Gas (DomGas) Unit and Export Pipeline

The DomGas Unit is designed for 300 Terajoules of sales gas per day (TJ/day), derived from Jansz feed gas. The unit uses MEG/Joule-Thomson (JT) processing to meet pipeline moisture and hydrocarbon dewpoint specifications. Domestic gas is exported via a dedicated pipeline to the mainland where it will tie in to the Dampier to Bunbury Natural Gas Pipeline.

Mercury is predicted to be in the feed gas that is diverted to the DomGas Unit after passing through the Inlet Systems. This gas is passed through an MRU to remove the Hg, thus ensuring that the DomGas produced meets the specification for gas to be received by the Dampier to Bunbury Natural Gas Pipeline.

3.3 GTP Ancillary Systems and Facilities

The main ancillary systems and facilities are listed in Sections 3.3.1 to 3.3.6.

3.3.1 Fuel Gas and Recycle Gas Systems

The Fuel Gas and Recycle Gas systems reliably provide fuel gas to users throughout the GTP, and return low-pressure gas, unsuitable for use as fuel, to the process for treating. The unit consists of multiple systems:

- high-pressure fuel gas system in each LNG train to supply the refrigerant GTs
- high-pressure fuel gas system in the Utilities Area to supply the gas turbine generators (GTGs) for power generation – an MRU is included on the start-up/backup fuel gas from the Inlet System to ensure the GTGs are operated free of Hg contamination
- high-pressure fuel gas is let down to separate low-pressure fuel gas headers to supply the Heating Medium Heaters and the pilots and the purge gas for the flare systems
- Recycle Gas system to compress flash gas from the AGRUs back to the process units for further treatment.

3.3.2 Power Generation System

The power generation system generates power for electrical consumers in the GTP and other areas (e.g. Permanent Operations Facility, Butler Park). The estimated total electrical power load for all electrical consumers is 416 MW (with contingency).

Electrical power is provided by five Frame 9 GTGs [N+1 operating philosophy], running continuously and sharing the load, between 80 and 100 MW each, under normal operating conditions. The maximum power output of the power generation plant under average feed composition/average ambient temperature (AFAT) operating conditions is 550 MW (fouled condition) with all five GTGs running.

3.3.3 Heating Medium System

The Heating Medium System is a pressurised, closed-loop hot demineralised water recirculating system. Heat is recovered from the available waste heat from the Frame 7 GT exhausts in the Waste Heat Recovery Units (WHRUs) and sent to various heat consumers around the GTP, including inlet gas heating, AGRU reboilers, MEG regeneration package, etc.

3.3.4 Pressure Relief/Liquids Disposal, Flare, and Vent Systems

The design of the flare system is based on the segregation of wet (containing water or water vapour), heavy hydrocarbons, and light, dry (water-free), potentially cold hydrocarbons so that hydrate formation, freezing, or condensation will not restrict the operation of any system. Three separate systems are provided for this purpose: wet flare, dry flare, and the BOG flare.

The design basis for the GTP specifies no routine flaring during normal operations other than flare pilots and purged gas (Ref. 36).

The wet and dry gas flare systems each comprise a collection header system for vapours and a collection header system for liquids, a knockout drum, and a staged ground flare, located north-west of the GTP. No liquid burners are installed. The BOG flare system comprises two 100% low-pressure flares (one operational, one spare) located near the LNG Storage Tanks.

The design basis for the GTP specifies no routine hydrocarbon venting and there are no routine vents provided on hydrocarbon process streams (Ref. 36).

Acid gas (CO_2) venting will occur if the carbon dioxide compression or injection system fails. The availability of the carbon dioxide compression and injection system, which can dispose (by underground injection) 100% of the volume of reservoir CO_2 to be removed during routine processing operations, is expected to be more than 80%, expressed as a five-year rolling average.

Venting of acid gas (and other constituents of MEG flash gas) may also occur if the MEG Flash Gas Compressor becomes unavailable.

3.3.5 Water Supply and Distribution

Fresh water will be supplied via the Reverse Osmosis (RO) Plant located within the General Utilities Area. A seawater intake caisson is part of the MOF offshore from Town Point. Fresh water may either be conditioned for use as potable and service water on the GTP, or demineralised further for use in the Heating Medium System.

3.3.6 Diesel Storage and Distribution

Diesel storage provides periodic diesel supply to these GTP consumers:

- emergency power and black-start generators
- freshwater and seawater fire pumps
- marine support vessels

- vehicle refuelling bay.

4 Atmospheric Pollutant Emission Sources

Table 4-1 lists the primary sources of the identified atmospheric pollutants and air toxics emissions for the GTP. Figure 4-1 shows the location of these emission sources in the current layout of the GTP.

Table 4-1: GTP Atmospheric Pollutants and Air Toxics Emission Sources

GTP Emission Sources	Associated Atmospheric Pollutants and Air Toxics
Frame 9 GTGs	NOx, PM_{10}, SO_2, NMVOCs[1], CO, Hg[4]
Frame 7 GTs	NOx, PM_{10}, SO_2, NMVOCs[1], CO, Hg[4]
Heating Medium Heaters	NOx, PM_{10}, SO_2, NMVOCs[1], CO, Hg[4]
Essential Diesel Power Generators	NOx, PM_{10}, SO_2, NMVOCs[2], CO
Wet and Dry Ground Flares	NOx, SO_2, NMVOCs[1], CO, Hg[4]
BOG Flares	NOx, SO_2, NMVOCs[1], CO, Hg[4]
Acid Gas Vents	NMVOCs[3], H_2S, Hg[4]
Condensate Storage Tanks (Fugitive Emissions)	NMVOCs, Hg[4]

Notes:

1. *NMVOCs associated with combustion of clean fuel gas in gas turbines, heaters (boilers) and flares consist mainly of the unburnt portion of the aliphatic hydrocarbons present in the fuel gas.*
2. *NMVOCs present in the exhaust gases from the Essential Diesel Power Generators also include minor (trace) quantities of PAHs and formaldehyde.*
3. *NMVOCs in the vented acid gas stream include up to 30% BTEX (on a molar basis).*
4. *Whilst Hg is present within the emission stream, it is at very low levels.*

Further to the list of atmospheric pollutants and air toxics shown in Table 4-1, ozone (O_3) may also be formed as a secondary atmospheric pollutant at ground level by the reaction of NO_2, VOCs, and sunlight.

Of the emissions sources listed in Table 4-1, CAPL has determined the following to be major emissions sources for the GTP:

- five 116 MW (nominal capacity) Frame 9 GTGs in the GTP power generation facility
- six 80 MW (nominal capacity) Frame 7 GTs, driving the refrigeration compressors within the GTP LNG trains
- two Heating Medium Heaters (boilers)
- Wet, Dry, and BOG Flares
- Acid Gas Vents within the AGRUs and associated CO_2 Injection Trains.

The Essential Diesel Power Generators are expected to be used infrequently and for short periods of time when the Frame 9 GTGs are unavailable, e.g. during GTP shutdowns and maintenance periods; hence, they are not considered to be major emission sources due to both the limited frequency of occurrence and overall volume of associated emissions. Similarly, the condensate storage tanks, diesel storage tanks, and other sources of fugitive emissions (such as valves, flanges, vents, connectors, pump seals and compressor seals in hydrocarbon service, flow lines, and connections) are also not considered to be major sources of emissions due to the expected low emission rates (fugitive emissions) of atmospheric pollutants and air toxics.

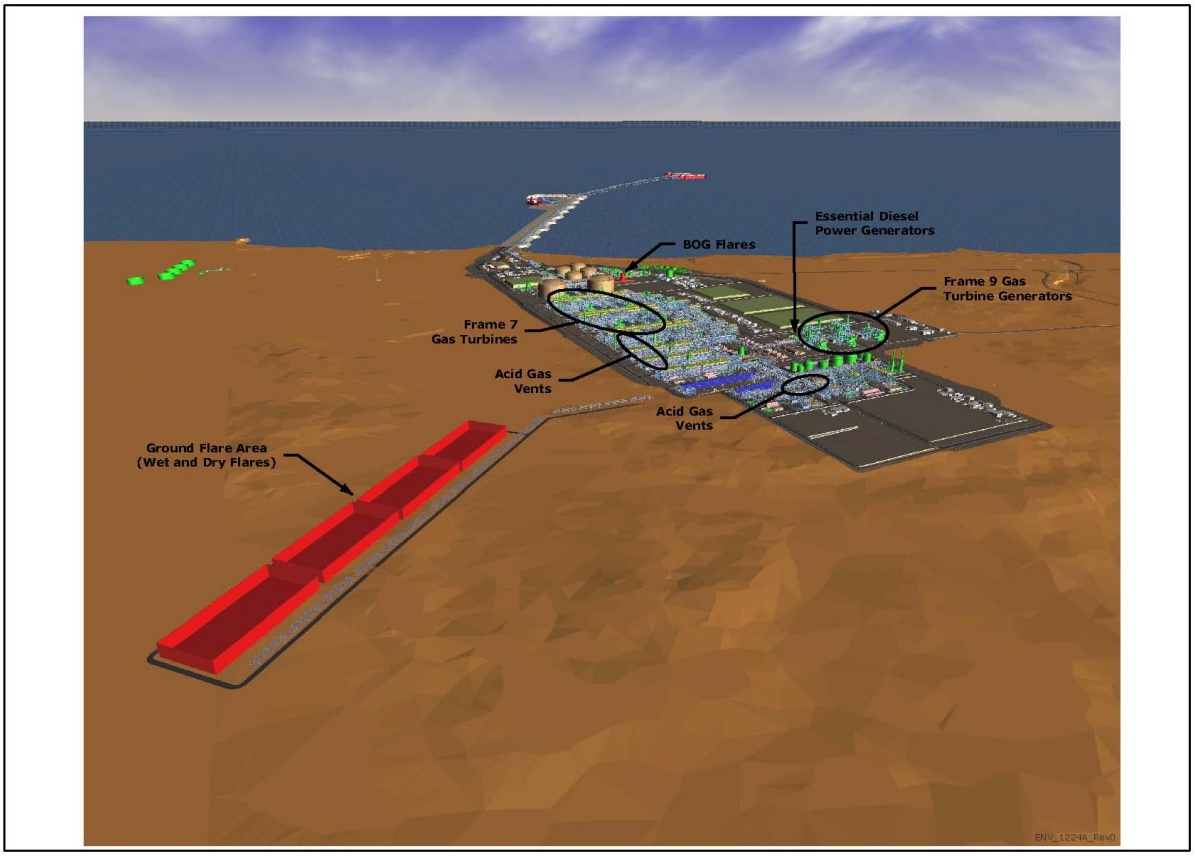


Figure 4-1: GTP Atmospheric Pollutant and Air Toxics Emission Sources

Where appropriate, emission targets have been adopted for the Gorgon Gas Development for selected major emission sources within the GTP, and these are outlined in Section 4.1.

4.1 Emission Targets

For the Gorgon Gas Development, emission targets have been set to prescribed standards of concentration for selected atmospheric pollutants at the point of discharge as specified in:

- EPA Guidance for the Assessment of Environmental Factors, Guidance Statement for Emissions of Oxides of Nitrogen from Gas Turbines (Ref. 37)
- NSW Protection of the Environment Operations (Clean Air) Amendment (Industrial and Commercial Activities and Plant) Regulations 2010.

Selected emission targets have been specified for major emissions sources where actual point source measurements can be taken safely. For the Gorgon Gas Development, this includes the Frame 9 GTGs, Frame 7 GTs, and Heating Medium Heaters. Table 4-2 lists the emission targets for selected atmospheric pollutants and air toxics emitted from the major emission sources that will be used during the operations phase.

Note: No emission targets are identified for the flare systems. The NSW Protection of the Environment Operations (Clean Air) Amendment (Industrial and Commercial Activities and Plant) Regulations 2010 specify emission values for flares and afterburners for the destruction of toxic substances or landfill gas (which could contain up to 50% CO_2 and other impurities). None of these emission

targets apply to the flare systems within the GTP, which burn clean and liquid-free hydrocarbon fuel—either fuel gas or process gas evacuated to the flare under upset process conditions. Furthermore, as noted above, emission targets are only specified for major emissions sources where actual point source measurements can be taken safely; in relation to the flare systems, taking these measurements is considered unsafe.

No emission targets are set for the acid gas vents. The AGRUs vent acid gas as per the acid gas stream composition, which is expected to vary depending on the composition of the well fluids and process conditions at the time of venting. However, sampling points to sample the composition of the acid gas stream have been provided to confirm the acid gas composition and assist with GHG and other environmental reporting requirements.

Table 4-2: Emission Targets

Emission Source	Atmospheric Pollutants and Air Toxics	Concentration[1] (mg/m^3)
GE Frame 9 GTGs	NOx[2]	70
	CO[3]	125
	NMVOC[4]	40
GE Frame 7 Process GTs Heating Medium Heaters	NOx[2]	350
	CO[3]	125
	NMVOC[4]	40

Note:

1. *Emission targets apply at the point of discharge to the environment.*
2. *Calculated as NO_2 at a 15% oxygen reference level, dry, at 0 °C and 101.3 kPa.*
3. *Calculated at 15% oxygen reference level, dry, at 0 °C and 101.3 kPa.*
4. *Calculated at 3% oxygen reference level, dry, at 0 °C and 101.3 kPa.*

5 Air Quality Modelling Studies

5.1 Introduction

CAPL has conducted several air quality modelling studies to assess potential impacts from atmospheric pollutants and air toxic emissions on local and regional air quality from the operation of the GTP. These studies are outlined in Table 5-1; the modelling results are summarised in Table 5-2 through Table 5-8.

More detailed information on the modelled scenarios and associated results for each completed study is provided in Sections 5.2 to 5.5.

Table 5-1: Summary of Completed Air Quality Modelling Studies

Year	Scope of Modelling	Model Used	Company Performing Modelling	Reference in Plan
2008	Modelling to estimate emissions of NOx, SO_2, PM_{10}, and O_3 during routine and non-routine operation of the GTP for both start-up and operation phases. Non-routine (or upset conditions) included cold start-up, emergency shutdown, and CO_2 venting. In addition, modelling to estimate emissions of H_2S during acid gas venting, and estimate nitrogen and sulfur deposition over the adjacent terrestrial and marine environments.	TAPM-GRS[1, 3]	Sinclair Knight Merz (SKM)	Ref. 36; Ref. 38
2010	Modelling and sensitivity testing to further improve the accuracy of predicted ground-level concentrations of NO_2 and O_3 by refining assumptions made in the 2008 modelling study.	TAPM-CTM[2, 3]	SKM	Ref. 39
2010	Modelling to estimate ground-level concentrations of H_2S and BTEX during acid gas venting for six selected release scenarios under a complete set of probable weather conditions.	Canary	Chevron Energy Technology Company (ETC)	Ref. 40
2014	Modelling to estimate ground-level concentrations of Hg and deposition on Barrow Island and in the adjacent ocean.	CALPUFF[4]	Air Assessments	Ref. 41
2017	Gorgon Emissions Verification Report Comparison of Measured Versus Predicted Emissions and Concentrations	N/A	Air Assessments	Ref. 42
2017	Gorgon Project Emissions Verification Report Modelling	N/A	Air Assessments	Ref. 43
2018	Modelling MEG Flash Vapour Compressor emission dispersion.	TAPM	Worley	Ref. 44
2019	Modelling to estimate ground-level concentrations of Hg and BTX incorporating the flaring of MEG flash vapour,	TAPM	Ramboll	Ref. 45

Year	Scope of Modelling	Model Used	Company Performing Modelling	Reference in Plan
2019	Gorgon MEG Flash to Flare Technical Note: update of the Ramboll 2019 (Ref. 46) Air quality assessment based on revised monitored and indicative flowrates and assesses the results against the applicable criteria.	N/A	Ramboll	Ref. 46

Notes:

1. *TAPM-GRS – The Air Pollution Model – Generalised Reaction Set*
2. *TAPM-CTM – The Air Pollution Model – Chemical Transfer Model*
3. *Note also that the 2008 and 2010 TAPM studies included the old location of the wet and dry ground flares in the south-west corner of the GTP. However, it is considered that the new location of the ground flares (as shown on Figure 4-1) will not have a discernible impact on the air quality modelling results*
4. *CALPUFF – Californian Puff Model*

Table 5-2: Summary of Maximum Predicted Pollutant Concentrations against NEPM Criteria (under all Modelled Operating Conditions) – 2008 SKM Modelling Study

Pollutant	TAPM-GRS Grid	Maximum on Grid (µg/m^3)	Averaging Period	Assessment Criteria (Table 2-1)		Percentage of Assessment Criteria
				ppm	µg/m^3	
Background Conditions						
NO_2	1 km	30.9 0.49	1 hour Annual	0.12 0.03	246 62	12.5 0.8
SO_2	1 km	1.08 0.19 0.02	1 hour 24 hour Annual	0.20 0.08 0.02	571 229 57	0.2 0.1 0.1
O_3	10 km	130.9 108.8	1 hour 4 hour	0.10 0.08	214 171	61.2 63.6
Routine Operating Conditions						
NO_2	1 km	42.6 0.7	1 hour Annual	0.12 0.03	246 62	17.3 1.2
SO_2	1 km	14.6 2.6 0.2	1 hour 24 hour Annual	0.20 0.08 0.02	571 229 57	2.6 1.2 0.3
PM_{10}	1 km	0.9	24 hour	--	50	1.8
O_3	10 km	131.9 109.6	1 hour 4 hour	0.10 0.08	214 171	61.6 64.1
Cold Start-up						
NO_2	1 km	341	1 hour	0.12	246	139
SO_2	1 km	14.8	1 hour	0.20	571	2.6
PM_{10}	1 km	1	24 hour	--	50	2
O_3	10 km	132.2	1 hour	0.10	214	61.8
Emergency Shutdown						
NO_2	1 km	37.5	1 hour	0.12	246	15.3

Pollutant	TAPM-GRS Grid	Maximum on Grid (µg/m^3)	Averaging Period	Assessment Criteria (Table 2-1)		Percentage of Assessment Criteria
				ppm	µg/m^3	
SO_2	1 km	9.1	1 hour	0.20	571	1.6
PM_{10}	1 km	0.7	24 hour	--	50	1.3
O_3	10 km	133.2	1 hour	0.10	214	62.2
Acid Gas Venting						
NO_2	1 km	42.6	1 hour	0.12	246	17.3
SO_2	1 km	14.9	1 hour	0.20	571	2.6
PM_{10}	1 km	2.3	24 hour	--	50	4.7
O_3	10 km	272	1 hour	0.10	214	127

Source: Ref. 38

Table 5-3: Summary of Maximum Predicted Pollutant Concentrations at Sensitive Receptor Locations (Chevron Camp and Butler Park) as percentage of NEPM Criteria – 2008 SKM Modelling Study

Pollutant	Averaging Period	Percentage of Assessment Criteria (%) (Table 2-1)				
		Background	Routine Operations	Cold Start-up	Emergency Shutdown	Acid Gas Venting
Chevron Camp						
NO_2	1 hour	6.1	8.1	33.3	6.5	7.7
SO_2	1 hour	0.1	0.9	0.7	0.5	0.9
PM_{10}	24 hour	n/a	0.6	0.6	0.6	1.6
O_3	1 hour	n/a	n/a	n/a	n/a	93.5
Butler Park						
NO_2	1 hour	7.3	8.5	33.3	8.5	8.5
SO_2	1 hour	0.1	1.1	1.1	0.5	1.1
PM_{10}	24 hour	n/a	0.6	0.7	0.6	1.6
O_3	1 hour	n/a	n/a	n/a	n/a	93.5

Source: Ref. 38

Table 5-4: Summary of Maximum Predicted Pollutant Concentrations against National Occupational Health Exposure Standards (under all modelled operating conditions) – 2008 SKM Modelling Study

Pollutant	Maximum on Grid (µg/m^3)	Averaging Period	TWA (µg/m^3) (Table 2-3)	Percentage of Assessment Criteria
Routine Operating Conditions				
NO_2	14.1	8 hour	5600	0.25
SO_2	6.3	8 hour	5200	0.12
Non-routine Operations – Cold Start-up				
NO_2	86.6	8 hour	5600	1.5
SO_2	5.7	8 hour	5200	0.11
Non-routine Operations – Emergency Shutdown				
NO_2	12.2	8 hour	5600	0.22
SO_2	4.4	8 hour	5200	0.08
Non-routine Operations – Acid Gas Venting				
NO_2	15.7	8 hour	5600	0.28
SO_2	6.3	8 hour	5200	0.12
H_2S	1774	8 hour	14 000	12.7

Source: Ref. 38

Table 5-5: Summary of Maximum Predicted O_3 and NO_2 Concentrations – 2010 SKM Modelling Study

		Maximum Predicted O_3 Concentrations			Assessment Criteria (Table 2-1)
		Base Case	Base Case plus 1 AGRU	Base Case plus 3 AGRUs	
One-hour Averaging Period	Maximum on Grid (µg/m^3)	140	147	167	214
	Percentage of Criteria (%)	65%	69%	78%	214
Four-hour Averaging Period	Maximum on Grid (µg/m^3)	119	119	125	171
	Percentage of Criteria (%)	70%	70%	70%	171

Averaging Period	Maximum Predicted NO_2 Concentration (µg/m^3) Base Case	Assessment Criteria (µg/m^3) (Table 2-1)
One-hour Averaging Period	20	246

Source: Ref. 38

Table 5-6: Summary of Maximum Predicted Pollutant Concentrations during Acid Gas Venting – Residential Criteria – 2010 ETC Modelling Study

Pollutant	Averaging Period	Maximum Ground-level Concentrations (ppb)		Assessment Criteria (ppb) (Table 2-4, Section 2.3.1.2)
		Butler Park	Chevron Camp	
Benzene	1 hour	1	<1	9
Toluene	1 hour	2	1	90
Ethylbenzene	1 hour	<1	<1	1 800
Xylene	1 hour	<1	<1	40
H_2S	Peak Concentration	<1	<1	1.0 – 3.5[1]

Source: Ref. 47

Notes:

1. *As noted in the NSW DEC's Approved Methods for Modelling and Assessment of Air Pollutants in New South Wales (Ref. 31), the impact assessment criterion for H_2S varies with population size (e.g. 2 people – 3.5 ppb; 10 people – 3.0 ppb; ~30 people – 2.5 ppb; ~125 people – 2 ppb; ~500 people – 1.5 ppb; >2000 people – 1.0 ppb).*

Table 5-7: Summary of Maximum Predicted Pollutant Concentrations during Acid Gas Venting – Occupational Criteria – 2010 ETC Modelling Study

Pollutant	Maximum Ground-level Concentrations (ppb)						Assessment Criteria – TWA[1] (ppb) (Table 2-3)
	GTP	Permanent Operations Facility	MOF	Terminal Tanks Site	Jetty	WA Oil Base	
Benzene	89	8	5	4	<1	<1	1000
Toluene	120	15	9.5	8	1	<1	100 000
Ethylbenzene	6	<1	<1	<1	<1	<1	100 000
Xylene	50	3	2	1	<1	<1	80 000
H_2S	28	6	4	3	<1	<1	5000

Source: Ref. 47

Note:

1. *The TWA concentration is measured over a normal eight-hour work day and a 40-hour work week, and is the concentration of an atmospheric contaminant to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.*

Table 5-8: Summary of Maximum Predicted Mercury Concentrations at Sensitive Receptor Locations (under all modelled operating conditions) – 2014 Air Assessments Modelling Study

Sensitive Receptor	Assessment Criteria (see Table 2-5 and Table 2-6, Section 2.3.3) ng/m³	Averaging Period	Maximum Ground-level Concentrations[1,2,6,7] (ng/m³) (Percentage of Criteria [%])			
			Routine Operations[3]	Routine Operations[3] (including Background Levels) [4]	Non-Routine Operations with 20% CO_2 Venting[5]	Non-Routine Operations with 20% CO_2 Venting[5] (including Background Levels) [4]
Residential Criteria						
Chevron Camp	1800	1-hour[5]	0.68 (0.038%)	2.68 (0.15%)	21 (1.2%)	23 (1.3%)
	200	Annual	0.0055 (0.0055%)	1.256 (0.63%)	0.04 (0.02%)	1.29 (0.65%)
Butler Park	1800	1-hour[5]	0.9 (0.0021%)	2.9 (0.16%)	34 (1.9%)	36 (2.0%)
	200	Annual	0.009 (0.05%)	1.259 (0.63%)	0.08 (0.04%)	1.33 (0.67%)
Occupational Criteria						
GTP	25 000	8-hour	2.2 (0.0088%)	4.2 (0.017%)	100 (0.4%)	102 (0.408%)
Permanent Operations Facility			1.7 (0.0068%)	3.7 (0.015%)	35 (0.14%)	37 (0.148%)
MOF			0.5 (0.002%)	2.5 (0.01%)	15 (0.06%)	17 (0.068%)
Terminal Tanks Site			0.65 (0.0026%)	2.65 (0.011%)	38 (0.15%)	40 (0.16%)
Jetty Head			0.23 (0.0009%)	2.23 (0.0089%)	10 (0.04%)	12 (0.048%)
WA Oil Base			0.18 (0.0007%)	2.18 (0.0087%)	20 (0.08%)	22 (0.088%)

Source: Ref. 41

Note:

1. *Concentrations and assessment criteria are presented in ng/m³ to aid in presentation of results, as the predicted ground-level concentrations are very low.*
2. *Concentrations are the total of elemental Hg, divalent Hg, and particulate Hg. More than 99% of the Hg emissions are associated with elemental Hg.*
3. *Routine operations do not include any CO_2 venting.*
4. *Background Hg levels are determined based on global emissions and comprise primarily elemental Hg. For the region near Barrow Island, anthropogenic sources should be minimal, with the largest local sources being emissions from soils, vegetation, and fires. Estimates of background levels across Australia were presented in a modelling study that included all known sources including industrial emissions and natural sources (Ref. 48). Annual predictions from this study indicate that for a location near Onslow a typical value is 1.25 ng/m³; with a shorter-term peak concentration of 2 ng/m³ being considered reasonable (Ref. 41).*
5. *Non-routine operations include 20% CO_2 venting (as a conservative estimate). To provide worst-case estimates of the 1-hour and 8-hour Hg concentrations, predictions were obtained from the model run assuming CO_2 venting occurs for every hour over a 3-year period. This ensured CO_2 venting would occur at the time of worst-case*

dispersion. The annual average concentration is based on 80% of the non-CO_2 venting model run and 20% of the result from the model run with CO_2 venting.

6. *The 1-hour criteria is the 99.9th percentile.*
7. *Non-routine shutdown and black-start conditions were also modelled; however, maximum ground-level concentrations at any grid point increased by a maximum of 0.10% from the modelled routine operations case, therefore, the results have not been included.*
8. *Annual Hg deposition rates were also modelled, with a maximum rate of 55 µg/m^2/year occurring within the GTP footprint (associated with non-routine operations with 20% CO_2 venting), without taking into account the re-emission of the highly volatile elemental Hg.*

The results of the air quality modelling studies were used to assess whether air quality at the identified sensitive receptor locations met the appropriate ambient air quality standards and standards for human health in the workplace for personnel working on Barrow Island, and to ensure that air pollutant and air toxic emissions from the GTP do not pose a risk of Material or Serious Environmental Harm to the flora, vegetation communities, terrestrial fauna, and subterranean fauna of Barrow Island. This is discussed in detail in Section 6.

In addition to the air quality modelling studies outlined in Table 5-1, the Gorgon Gas Development has been the subject of a number of risk assessments. Of particular importance are the:

- screening-level health risk assessment (HRA) (Ref. 40), which was undertaken to evaluate potential human health risks specifically associated with acid gas venting (as outlined in Section 6.2.6)
- screening-level terrestrial ecological risk assessment (ERA) (Ref. 49) and marine ERA (Ref. 50), which were undertaken to assess potential environmental impacts to terrestrial and marine flora and fauna (as outlined in Section 6.2.7)
- screening-level HRA and ERA (Ref. 51), which were undertaken to evaluate potential human health risks and environmental impacts specifically associated with Hg emissions (as outlined in Sections 6.2.8 and 6.2.9).

The results of the completed modelling studies, HRAs, and ERAs were used to verify that adequate best practice pollution control measures were identified and implemented in the design to minimise emissions from the GTP, and, where necessary, to identify additional air quality management measures (see Section 7) required to further support the implementation of these best practice measures.

The air quality modelling data and associated information were also used to develop the ambient air quality monitoring program outlined in Section 9.

5.2 SKM Air Quality Modelling Studies 2008

5.2.1 TAPM-GRS Air Quality Modelling

The atmospheric dispersion model TAPM-GRS (version 3.0.7) was used for the initial modelling assessment of the GTP (Ref. 36; Ref. 38). TAPM is a prognostic three-dimensional model designed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) that can be used to predict meteorological and air pollution parameters on an hourly basis. The model predicts flows that are important to local-scale air pollution, such as sea breezes and terrain-induced flows. The meteorological parameters predicted by the model were subsequently validated against actual regional background air quality modelling and monitoring results for the Pilbara airshed. Appendix A summarises the regional background air quality for the Pilbara airshed.

The TAPM-GRS model was first run to generate predictions of background air quality on Barrow Island (pre-Gorgon GTP start-up), and then routine (steady state) and three non-routine operating scenarios were modelled to assess potential impacts arising from emissions from the GTP. The three non-routine operating conditions modelled included start-up of the GTP after a prolonged shutdown (i.e. a cold start-up), an emergency shutdown, and a CO_2 Injection System failure resulting in acid gas venting at the GTP.

The modelling included assessment of impacts from NO_2, SO_2, PM_{10}, O_3, and H_2S.

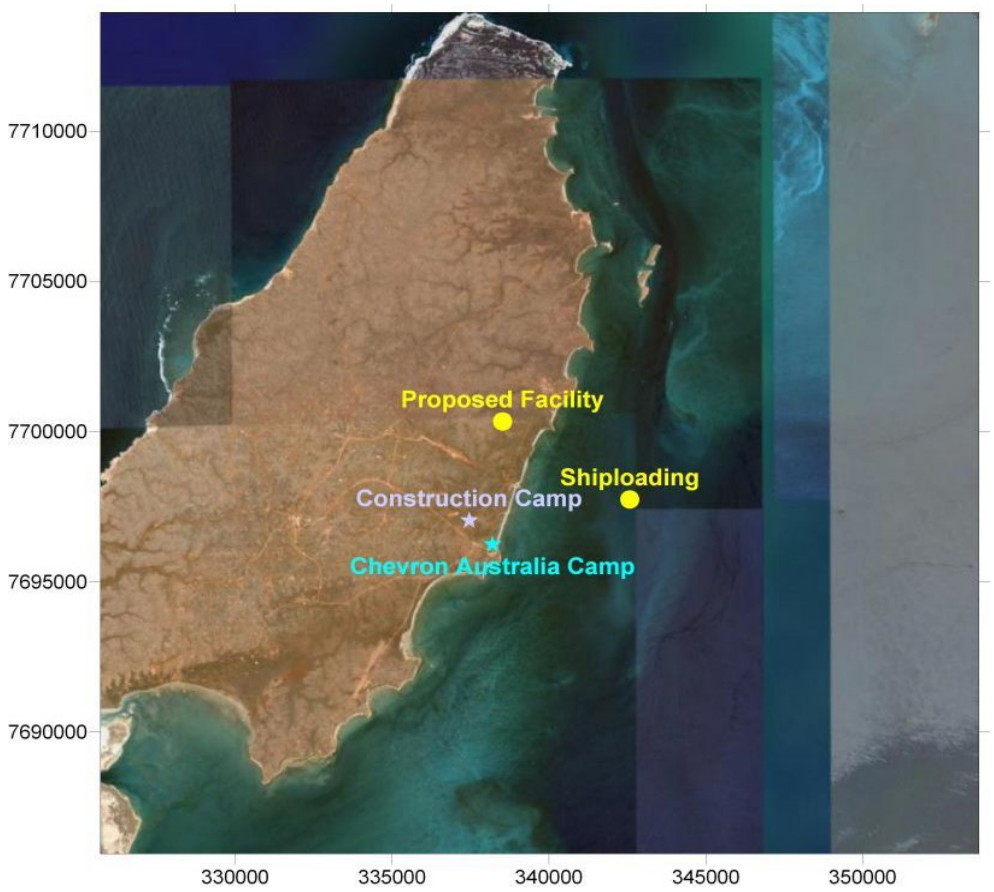
A summary of the modelling results is presented in Sections 5.2.2.2 to 5.2.2.9, and detailed discussion on the modelling results is provided in Section 6.

5.2.2 Summary of TAPM-GRS Air Quality Modelling Results

5.2.2.1 Model Inputs

The key inputs to the TAPM-GRS model included:

- existing air quality data (or background data) for existing and approved future emissions sources, including the existing WA Oil Facilities on Barrow Island, North West Shelf Venture Karratha Gas Plant including Train 4 and Train 5, the approved Pluto Gas Plant, the Hamersley Iron Power Station at Parker Point near Dampier, shipping emissions associated with the Burrup Peninsula, and Burrup Fertiliser's Ammonia Plant
- emission parameters from point source emission sources within the GTP for both the routine and non-routine operating scenarios
- emission parameters from commercial shipping sources
- Barrow Island meteorological data
- Barrow Island terrain data
- selected sensitive receptor locations on Barrow Island, including the Chevron Camp and Butler Park. These sensitive receptor locations are shown on Figure 5-1 in relation to the GTP and the location of ship-loading activities.



Source: Ref. 38

Note: Construction Camp is now known as Butler Park.

Figure 5-1: Location of Sensitive Receptors Relative to the Location of the GTP and Ship-loading Operations

5.2.2.2 Modelled Background Air Quality Results

The modelled background air quality results for the Pilbara Region, including Barrow Island and its surrounding marine environment (on a 3 km grid), are summarised in Table 5-9. The results are expressed as maximum values on the grid, but these do not necessarily occur close to Barrow Island.

Table 5-9: Maximum Predicted Background Atmospheric Pollutant Concentrations from Existing and Approved Regional Emission Sources

Pollutant	TAPM-GRS Grid	Maximum on Grid ($\mu g/m^3$)	Averaging Period	Assessment Criteria (Table 2-1)		Percentage of Assessment Criteria
				ppm	$\mu g/m^3$	
NO_2	1 km	30.9 0.49	1 hour Annual	0.12 0.03	246 62	12.5 0.8
SO_2	1 km	1.08 0.19 0.02	1 hour 24 hour Annual	0.20 0.08 0.02	571 229 57	0.2 0.1 0.1
O_3	10 km	130.9 108.8	1 hour 4 hour	0.10 0.08	214 171	61.2 63.6

Source: Ref. 38

The modelled background air quality results at the sensitive receptor locations are summarised below.

Barrow Island experiences very low concentrations of NO_2 derived mainly from existing sources on the Island. For example, the modelling indicated that the Chevron Camp had a predicted one-hour maximum NO_2 concentration of 15 µg/m^3, which is 6.1% of the relevant NEPM criteria; and an annual average concentration of approximately 0.18 µg/m^3, which is 0.3% of the annual NEPM criteria.

Predicted background SO_2 concentrations on Barrow Island are also very low. For example, the Chevron Camp recorded a maximum one-hour concentration of SO_2 of 0.52 µg/m^3, which is equivalent to 0.1% of the applicable NEPM criteria. The 24-hour and annual average SO_2 background concentrations at the Chevron Camp were predicted to be 0.04% and 0.02% of the relevant NEPM criteria respectively.

The maximum predicted one- and four-hour O_3 concentrations from the existing and approved sources in the coastal Pilbara Region occur around the Burrup Peninsula and inland to the south of the Peninsula, as nearly all NOx and VOC emissions are derived from sources located in these regions. On Barrow Island, the background O_3 concentrations are almost half the maximum predicted concentrations for each averaging period.

Background PM_{10} concentrations were not modelled in the study; however, they are not expected to be significant on Barrow Island because the Island is approximately 55 km from the Pilbara coast and located in a marine environment where it could be expected that PM_{10} concentrations would be significantly lower.

A comparison of the modelling results for the two sensitive receptor locations is summarised in Table 5-16.

5.2.2.3 Modelled Routine Operations Air Quality Results

Routine operations were modelled based on the following operational status of the major atmospheric pollutant emissions sources operating conditions:

- all five Frame 9 GTGs operating
- all six Frame 7 GTs operating
- one Heating Medium Heater maintained on hot stand-by and one on cold stand-by
- Wet and Dry Gas flares operated on pilot and purge fuel gas only; no non-routine flaring
- BOG flares operated on pilot and purge fuel gas only; no non-routine flaring
- no acid gas venting at the AGRU trains; all acid gas injected
- continuous emissions from shipping activities, including those from infield support vessels, and LNG and condensate carriers.

The air quality modelling results for maximum predicted ground-level concentrations during routine operations are summarised in Table 5-10.

Table 5-10: Maximum Predicted Atmospheric Pollutant Concentrations (Routine Operating Conditions)

Pollutant	TAPM-GRS Grid	Maximum on Grid (µg/m^3)	Averaging Period	Assessment Criteria (Table 2-1)		Percentage of Assessment Criteria
				ppm	µg/m^3	
NO_2	1 km	42.6 0.7	1 hour Annual	0.12 0.03	246 62	17.3 1.2
SO_2	1 km	14.6 2.6 0.2	1 hour 24 hour Annual	0.20 0.08 0.02	571 229 57	2.6 1.2 0.3
PM_{10}	1 km	0.9	24 hour	--	50	1.8
O_3	10 km	131.9 109.6	1 hour 4 hour	0.10 0.08	214 171	61.6 64.1

Source: Ref. 38

The modelled air quality results during routine operations at the sensitive receptor locations are summarised below.

The Chevron Camp has a maximum predicted one-hour NO_2 concentration of 20 µg/m^3, which is 5 µg/m^3 above background levels, and is 8.1% of the relevant NEPM criteria. Butler Park has a predicted concentration of 21 µg/m^3 or 8.5% of the NEPM criteria.

The Chevron Camp has a maximum predicted annual average NO_2 concentration of approximately 0.18 µg/m^3, which is 0.3% of the relevant NEPM criteria, while Butler Park has a maximum predicted annual average concentration of 0.22 µg/m^3, which corresponds to 0.4% of the NEPM criteria.

The Chevron Camp has a maximum predicted one-hour concentration of SO_2 of 5 µg/m^3 while Butler Park has a maximum predicted one-hour concentration of 6.1 µg/m^3, which are equivalent to 0.9% and 1.1% of the applicable NEPM criteria, respectively.

The predicted 24-hour and annual average concentrations of SO_2 at the Chevron Camp were predicted to be 0.2% and 0.1% of the relevant NEPM criteria, respectively. At Butler Park, the 24-hour and annual average concentrations were predicted to be 0.3% and 0.1% of the relevant NEPM criteria, respectively.

There is a slight increase in the maximum predicted one- and four-hour O_3 concentrations from the routine operation of the GTP when compared to background levels.

The maximum 24-hour PM_{10} concentrations at both the Chevron Camp and Butler Park are predicted to be 0.3 µg/m^3, which is equivalent to 0.6% of the NEPM criteria.

A comparison of the modelling results for the two sensitive receptor locations is summarised in Table 5-16.

5.2.2.4 Modelled Non-routine (Cold Start-up) Air Quality Results

It is expected that an LNG train within the GTP may be shut down for sufficient time to require a cold start at least once a year. A cold restart of a train is expected to take approximately six hours, during which time approximately 30% of

the normal flow rate of that LNG train is expected to be directed to the wet flare as the LNG is brought to product specification. This scenario was modelled based on the following operational status of the major atmospheric pollutant emissions sources operating conditions:

- four Frame 9 GTGs operating; one Frame 9 GTG out of service
- four (LNG Train 1 and 2) Frame 7 GTs operating; two Frame 7 GTs out of service (LNG Train 3)
- one Heating Medium Heater operating at full design rate to provide for the shortfall in process heat due to the WHRU on LNG Train 3 being switched off; second Heating Medium Heater on cold stand-by
- 30% of the normal gas rate through the LNG Trains diverted to the wet flare; dry flares operated on pilot and purge fuel gas only
- BOG flares operated on pilot and purge fuel gas only; no non-routine flaring
- no acid gas venting at the AGRU trains; all acid gas injected
- continuous emissions from shipping activities, including those from infield support vessels, and LNG and condensate carriers.

The air quality modelling results for maximum predicted ground-level concentrations during cold start-up operations are summarised in Table 5-11.

Table 5-11: Maximum Predicted Atmospheric Pollutant Concentrations (Cold Start-up)

Pollutant	TAPM-GRS Grid	Maximum on Grid (µg/m^3)	Averaging Period	Assessment Criteria (Table 2-1)		Percentage of Assessment Criteria
				ppm	µg/m^3	
NO_2	1 km	341	1 hour	0.12	246	139
SO_2	1 km	14.8	1 hour	0.20	571	2.6
PM_{10}	1 km	1	24 hour	--	50	2
O_3	10 km	132.2	1 hour	0.10	214	61.8

Source: Ref. 38

The maximum predicted one-hour NO_2 concentration is 139% of the NEPM criteria and occurs immediately north-east of the GTP. The cause of this high concentration is due to the high NO_2 emissions as approximately 30% of the normal flow rate of a single LNG train may be directed to the flare as the LNG is brought to product specification. However, analysis of the output file from the model indicates that this high concentration only occurs for one hour, and that the second highest concentration is only 72% of the NEPM criteria.

However, the Chevron Camp and Butler Park both have maximum predicted one-hour NO_2 concentrations of 82 µg/m^3, which is 33.3% of the relevant NEPM criteria.

In light of these modelling results for NO_2 and feedback received from the DEC during the initial review process for this Plan (Ref. 52), CAPL undertook additional modelling for NO_2 to further improve the accuracy of predicted ground-level concentrations. This modelling work is outlined in Section 5.3.

The Chevron Camp has a maximum predicted one-hour concentration of SO_2 of 3.9 µg/m^3 while Butler Park has a maximum predicted one-hour concentration of 6.4 µg/m^3, both of which are well below the applicable NEPM criteria.

There is an increase in the maximum predicted one- and four-hour O_3 concentrations from the cold start-up scenario of the GTP when compared to routine operating conditions; however, this occurs to the immediate south of Barrow Island.

The maximum predicted 24-hour PM_{10} concentrations at both the Chevron Camp and Butler Park are predicted to be below 1.0% of the NEPM criteria.

A comparison of the modelling results for the two sensitive receptor locations is summarised in Table 5-16.

5.2.2.5 Modelled Non-routine (Emergency Shutdown) Air Quality Results

Emergency shutdown of the GTP due to various process upsets was also modelled as a credible non-routine operating scenario.

Unplanned emergency shutdowns are anticipated to occur fewer than ten times in the first year of operation and involve less than one hour of non-routine flaring, reducing to six events per year over the subsequent years. In addition to these events, there are other process upset events that could result in non-routine flaring, but not necessarily during emergency shutdowns.

During a typical operating year, non-routine flaring has been estimated to occur on average for 135 hours for the Dry and Wet flares combined (Ref. 53). It is also expected that the frequency and duration of non-routine flaring events would reduce over time as plant operating knowledge builds up and plant performance and efficiency improve.

This scenario was modelled based on the following operational status of the major atmospheric pollutant emissions sources operating conditions:

- four Frame 9 GTGs operating; one Frame 9 GTG tripped (unoperational)
- four (LNG Train 1 and 2) Frame 7 GTs operating; two Frame 7 GTs tripped (unoperational) [LNG Train 3]
- one Heating Medium Heater maintained on hot stand-by; second Heating Medium Heater on cold stand-by
- 100% of the normal gas flow rate through tripped LNG Train 3 diverted to one of the Dry flares; the other Dry and Wet flares operated on pilot and purge fuel gas only
- BOG flares operated on pilot and purge fuel gas only; no non-routine flaring
- no acid gas venting at the AGRU trains; all acid gas injected
- no emissions from shipping activities.

The air quality modelling results for maximum predicted ground-level concentrations during emergency shutdown are summarised in Table 5-12.

Table 5-12: Maximum Predicted Atmospheric Pollutant Concentrations (Emergency Shutdown)

Pollutant	TAPM-GRS Grid	Maximum on Grid (µg/m³)	Averaging Period	Assessment Criteria (Table 2-1)		Percentage of Assessment Criteria
				ppm	µg/m³	
NO_2	1 km	37.5	1 hour	0.12	246	15.3
SO_2	1 km	9.1	1 hour	0.20	571	1.6
PM_{10}	1 km	0.7	24 hour	--	50	1.3
O_3	10 km	133.2	1 hour	0.10	214	62.2

Source: Ref. 38

The maximum predicted one-hour NO_2 concentration on grid decreased from 42.6 µg/m³ (for routine operations) to 37.5 µg/m³, which is equivalent to 15.3% of the NEPM criteria.

The Chevron Camp has a maximum predicted one-hour NO_2 concentration of 16 µg/m³, and Butler Park has a predicted concentration of 21 µg/m³, both of which are well below the NEPM criteria.

When the modelling results for the maximum predicted one-hour concentration of SO_2 are compared to the results for the routine operating conditions, it is evident that the concentrations of SO_2 have decreased. The cause of this reduction is due to the shutdown of two of the Frame 7 GTs and the cessation of shipping emissions during this period.

Both the Chevron Camp and Butler Park have a maximum predicted one-hour concentration of SO_2 of 3 µg/m³, which is equivalent to 0.5% of the applicable NEPM criteria.

There is almost no change in the maximum predicted one- and four-hour O_3 concentrations from the emergency shutdown operating scenario when compared to the routine operating scenario.

The maximum predicted 24-hour PM_{10} concentrations at both the Chevron Camp and Butler Park are predicted to be 0.29 µg/m³, which is equivalent to 0.6% of the NEPM criteria.

A comparison of the modelling results for the two sensitive receptor locations is summarised in Table 5-16.

5.2.2.6 Modelled Non-routine (Acid Gas Venting) Air Quality Results

During routine operations, acid gas is to be injected into the Dupuy Formation beneath Barrow Island. Non-routine acid gas venting could occur as a result of planned and unplanned events (Ref. 54). These are briefly described below.

Planned acid gas venting events during operations may arise as a result of:

- Planned maintenance of a CO_2 compressor. Single compressor maintenance activity is forecast to occur once every two years, for a period of up to four days, with venting at Acid Gas Vent 1 (see Figure 5-2).
- CO_2 pipeline inspection/maintenance, expected to occur at most once every five years. 100% of the combined acid gas removed through the three AGRUs may be vented through Acid Gas Vent 1 for approximately five days.

- De-inventorying the CO_2 pig launcher (through venting at Acid Gas Vent 4 – see Figure 5-2) following pigging of the CO_2 pipeline to allow access into the vessel. Duration of venting is likely to be fewer than two hours and predicted to occur no more than once in five years.

Unplanned acid gas venting events during operations may arise as a result of:

- Process trip of a single CO_2 compressor. Process trip/upset scenarios are considered to occur infrequently, i.e. four to six times per year per compressor. Where appropriate, the compressors are designed to restart from a pressurised condition, as each trip could result in up to four hours of venting at Acid Gas Vent 1 for 50% of the acid gas removed by the affected AGRU.
- Process trip affecting both CO_2 compressors in an AGRU train. A process trip causing both compressors to trip is considered very infrequent, once per year, during which time 100% of the volume of acid gas removed by the affected AGRU would be vented for a period up to four hours at Acid Gas Vent 1.
- Loss of Gorgon feed gas (which may occur at a maximum frequency of once every two years). In this case, the CO_2 compressors would either be shut down or put into recycle mode and the acid gas vented through Acid Gas Vent 1 (due to the low flow).
- High back-pressure from CO_2 wells resulting in high suction pressure to the compressor. This scenario deals with injectivity problems and could occur as a result of several causes, e.g. single well unavailability due to well workover (anticipated to occur once a year per well and involve five days of venting at 11% of the volume of acid gas removed by the affected AGRU) through to unavailability of all four wells at a drill centre (this equates to venting 44% of the total flow from the three trains at Acid Gas Vent 1).
- Process upset conditions on the low-pressure side of the CO_2 compression unit, resulting in venting through Acid Gas Vent 2 (see Figure 5-2). Such conditions could include, for example, gas breakthrough on liquid circuit, check valve leakage, or compressor blowdown either for maintenance or an emergency (e.g. seal leak). Such events should be rare and of short duration; i.e. between 15 and 30 minutes.
- Process upset conditions on the high-pressure side of the CO_2 compression unit, resulting in venting through Acid Gas Vent 3 (see Figure 5-2). A typical emergency includes a compressor blowdown either for maintenance or an emergency (e.g. seal leak). Each compressor may require a blowdown once every two years for maintenance. Venting associated with this scenario is not expected to exceed 30 minutes at a time.
- MEG Flash Gas Compressor trip resulting in venting at Acid Gas Vent 6 (see Figure 5-2), which is located on the suction line to the MEG Flash Gas Compressor.

Acid gas venting events during commissioning and start-up of the GTP may arise as a result of:

- Initial Train 1 start-up commences with Jansz feed gas at 30% of the full gas flow through the Train. As it is not possible to operate the CO_2 compressors with this low flow, acid gas is vented through Acid Gas Vent 1, with this scenario likely to continue for up to a week until full flow is established through the Train.

- Following initial start-up of Train 1, operation with the peak Jansz flow would continue for AGRU Train 1 until Gorgon gas is introduced. Therefore, venting at this rate through Acid Gas Vent 1 may continue for up to six months, with additional venting via Acid Gas Vent 6.

Figure 5-2 shows the locations of each of the acid gas vents within the GTP.

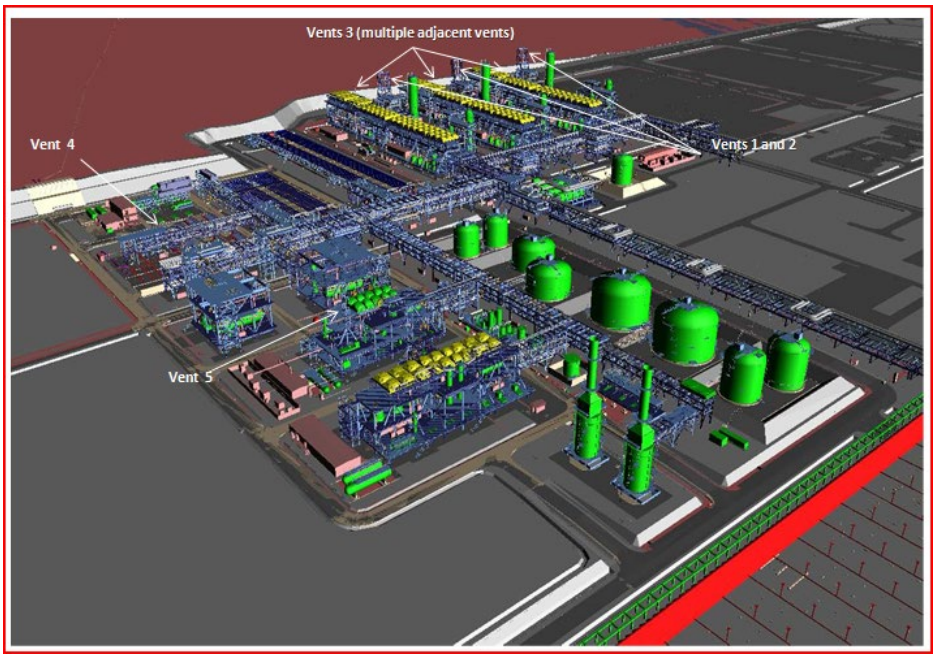


Figure 5-2: Location of Acid Gas Vents at the GTP

Table 5-13 summarises typical venting scenarios and the location of each vent

Table 5-13: Acid Gas Vents Location and Intended Use

Vent No.	Vent Description and Location	Intended Use
Vent 1	Main low-pressure acid gas vent stack from the discharge of the Amine Regenerator Reflux Drum Vent in each of the AGRUs (three in total)	During planned maintenance or a process trip condition (e.g. a CO_2 injection compressor trip) or when the entire CO_2 compression train or injection wells are unavailable. Worst-case scenario is venting from all three AGRU Reflux Drums due to CO_2 Injection Pipeline inspection/maintenance
Vent 2	Secondary low-pressure acid gas vent stack for emergency/process upset venting from the CO_2 compression unit—Vent 2 is co-located with Vent 1 in each of the AGRUs (three in total)	When de-pressuring the low-pressure end of the CO_2 compression system in emergency/process upset conditions
Vent 3	Local vents for the high-pressure CO_2 compression system (three sets of vents in total)	When de-pressuring the high-pressure CO_2 compression system (fourth stage compressor drum and discharge)
Vent 4	CO2 Injection Pipeline pig receiver/launcher vent (one in total)	During CO_2 pipeline pigging operations
Vent 6	Low-pressure vent upstream of MEG Flash Gas Compressor (one in total)	When the MEG Flash Gas Compressor is not available,

Table 5-14 lists the estimated volumes of acid gas to be injected and vented. It is expected that with the build-up of operational experience, acid gas venting events will reduce in frequency and duration, such that by approximately year six into the GTP operation, a long-term performance target of injecting 95% of the volume of acid gas produced can be maintained.

Table 5-14: Estimated Volumes of Acid Gas Anticipated to be Injected and Vented

Percentage of Acid Gas (Reservoir CO_2)	Year 1	Year 2–5	Year 6+	Long-term Performance Target
Percentage of Acid Gas injected into the Dupuy Formation	60–90% p.a. (2.52–3.78 MTPA)	70–95% p.a. (2.94–3.99 MTPA)	80–95% p.a. (3.36–3.99 MTPA)	95% p.a. (3.99 MTPA)
Acid Gas vented due to scheduled maintenance and unplanned facilities downtime	5–15% p.a. (0.21–0.63 MTPA)	5–10% p.a. (0.21–0.42 MTPA)	3–5% p.a. (0.13–0.21 MTPA)	3% p.a. (0.13 MTPA)
Acid Gas vented due to unforeseen reservoir constraints (including well injectivity failure)	0–25% p.a. (0–1.05 MTPA)	0–20% p.a. (0–0.84 MTPA)	0–15% p.a. (0–0.63 MTPA)	2% p.a. (0.08 MTPA)

Notes:

- *As the concentration of CO_2 varies in different parts of the Gorgon Gas Field, these figures represent the anticipated maximum annual rate of 4.2 MTPA (Ref. 21).*
- *The availability of the CO_2 compression and injection system, which is capable of disposing by underground injection 100% of the volume of reservoir CO_2 to be removed during routine processing operations, is expected to be more than 80% expressed as a five-year rolling average (despite not being able to inject CO_2 during initial start-up and Jansz-only operations, with a long-term target of 95% or more (in compliance with Condition 26 of MS 800).*
- *The concentration of H_2S within the acid gas stream is approximately 200 ppmv maximum.*

The 2008 SKM modelling study (Ref. 38) only modelled continuous simultaneous acid gas venting from the three AGRUs through Acid Gas Vent 1 in each train. This non-routine scenario was modelled based on the following operational status of the major atmospheric pollutant emissions sources operating conditions:

- all five Frame 9 GTGs operating in an N+1 mode
- all six Frame 7 GTs operating
- one Heating Medium Heater maintained on hot stand-by (pilot flame only) and one Heating Medium Heater on cold stand-by
- Wet and Dry flares operating on pilot and purge fuel gas only; no non-routine flaring
- BOG flares operating on pilot and purge fuel gas only; no non-routine flaring
- continuous simultaneous acid gas venting at all three AGRUs; no acid gas injection
- continuous emissions from shipping activities, including those from infield support vessels, and LNG and condensate carriers.

The above-modelled scenario is considered most representative of:

- the planned event of CO_2 pipeline inspection/maintenance, expected to occur once in five years with a venting duration of five days, or
- an unplanned event involving CO_2 pipeline failure, which is not expected to occur during the life of the Gorgon Gas Development.

The air quality modelling results for maximum predicted ground-level concentrations during simultaneous acid gas venting from the three AGRUs are summarised in Table 5-15.

Table 5-15: Maximum Predicted Atmospheric Pollutant Concentrations (Acid Gas Venting)

Pollutant	TAPM-GRS Grid	Maximum on Grid (µg/m^3)	Averaging Period	Assessment Criteria (Table 2-1)		Percentage of Assessment Criteria
				ppm	µg/m^3	
NO_2	1 km	42.6	1 hour	0.12	246	17.3
SO_2	1 km	14.9	1 hour	0.20	571	2.6
PM_{10}	1 km	2.3	24 hour	--	50	4.7
O_3	10 km	272	1 hour	0.10	214	127

Source: Ref. 38

The modelled air quality results during acid gas venting at the sensitive receptor locations are summarised below.

The Chevron Camp has a maximum predicted one-hour NO_2 concentration of 19 µg/m^3, and Butler Park has a predicted concentration of 21 µg/m^3, both of which are well below the NEPM criteria.

When the modelling results for the maximum predicted one-hour concentration of SO_2 are compared to the results for the routine operating conditions, it is evident that there have been no changes in concentrations of SO_2. The Chevron Camp had a maximum predicted one-hour concentration of SO_2 of 5 µg/m^3 and Butler Park had a maximum predicted one-hour concentration of SO_2 of 6.1 µg/m^3, which are equivalent to 0.9% and 1.1% of the applicable NEPM criteria, respectively.

The scenario modelled involved continuous simultaneous acid gas venting at all three AGRUs at the maximum expected acid gas removal rate each day for 365 days a year, which is not expected to occur during the life of the Gorgon Gas Development. This scenario resulted in a maximum predicted one-hour concentration of O_3 of 272 µg/m^3, which is equivalent to 127% of the applicable NEPM criteria. Out of the top ten O_3 concentrations predicted to occur during this scenario, the highest and second highest concentrations were above the one-hour NEPM criterion, with all subsequent concentrations predicted to be below the one-hour NEPM criterion.

These modelling results also indicated that even with continuous simultaneous acid gas venting at maximum acid gas removal rates over an entire year, the maximum predicted one-hour O_3 concentrations at the both the Chevron Camp and Butler Park would be 200 µg/m^3, which is equivalent to 93.5% of the applicable NEPM criteria. As this type of non-routine scenario is expected to occur at most once every five years, and only for approximately five days, the potential for these high concentrations of O_3 in the ambient environment is considered to be very low.

In light of these conservative modelling results, and feedback received from the DEC during the initial review process for this Plan (Ref. 55), CAPL has since undertaken additional modelling for O_3 to further improve the accuracy of predicted ground-level concentrations. This modelling work is outlined in Section 5.3, and detailed discussion on the modelling results to date is provided in Section 6.

The maximum predicted 24-hour PM_{10} concentrations at both the Chevron Camp and Butler Park are predicted to be 0.8 µg/m^3, which is equivalent to 1.6% of the NEPM criteria.

A comparison of the modelling results for the two sensitive receptor locations is summarised in Table 5-16.

5.2.2.7 Summary of Modelled Air Quality Results at the Sensitive Receptor Locations

The modelling results for the two sensitive receptor locations (Chevron Camp and Butler Park) showed no exceedance of the NEPM criteria for any of the atmospheric pollutants or air toxics modelled. A comparison of the results, as a percentage of the relevant assessment criteria, is summarised in Table 5-16.

Table 5-16: Comparison of Maximum Predicted Pollutant Concentrations at Sensitive Receptor Locations (as percentage of NEPM Criteria)

Pollutant	Averaging Period	Percentage of Assessment Criteria (%) (Table 2-1)				
		Background	Routine Operations	Cold Start-up	Emergency Shutdown	Acid Gas Venting
Chevron Camp						
NO_2	1 hour	6.1	8.1	33.3	6.5	7.7
SO_2	1 hour	0.1	0.9	0.7	0.5	0.9
PM_{10}	24 hour	n/a	0.6	0.6	0.6	1.6
O_3	1 hour	n/a	n/a	n/a	n/a	93.5
Butler Park						
NO_2	1 hour	7.3	8.5	33.3	8.5	8.5
SO_2	1 hour	0.1	1.1	1.1	0.5	1.1
PM_{10}	24 hour	n/a	0.6	0.7	0.6	1.6
O_3	1 hour	n/a	n/a	n/a	n/a	93.5

Source: Ref. 38

5.2.2.8 Comparison of Ambient Air Quality Modelling Results to National Occupational Health Exposure Standards

The TAPM-GRS model was also used to generate predictions of ambient air quality results under routine and non-routine operating conditions to assess potential impacts arising from emissions from the GTP when compared to the relevant National Occupational Health Exposure Standards set by SWA (see Table 2-3). The modelling included the assessment of impacts from NO_2, SO_2, and H_2S.

A comparison of the results is summarised in Table 5-17; all modelled ambient air quality results were found to be well below the relevant National Occupational Health Exposure Standards.

Table 5-17: Comparison of Maximum Predicted Ground-level Atmospheric Pollutant Concentrations against National Occupational Health Exposure Standards (under all modelled operating conditions)

Pollutant	Maximum on Grid (µg/m^3)	Averaging Period	TWA (µg/m^3) (Table 2-3)	Percentage of Assessment Criteria
Routine Operating Conditions				
NO_2	14.1	8 hour	5600	0.25
SO_2	6.3	8 hour	5200	0.12
Non-routine Operations – Cold Start-up				
NO_2	86.6	8 hour	5600	1.5
SO_2	5.7	8 hour	5200	0.11
Non-routine Operations – Emergency Shutdown				
NO_2	12.2	8 hour	5600	0.22
SO_2	4.4	8 hour	5200	0.08
Non-routine Operations – Acid Gas Venting				
NO_2	15.7	8 hour	5600	0.28
SO_2	6.3	8 hour	5200	0.12
H_2S	1774	8 hour	14 000	12.7

Source: Ref. 38

The 2008 SKM modelling studies predicted a maximum eight-hour H_2S concentration of 1744 µg/m^3 during acid gas venting, and indicated that an H_2S gas plume could form with concentrations of up to 800 µg/m^3 in the immediate vicinity of the AGRU vent. Additionally, the studies predicted concentrations of approximately 200 µg/m^3 potentially extending offsite covering a relatively large area north-east of the GTP and south to the Chevron Camp and Butler Park, where the predicted H_2S concentrations could persist for periods of up to 90 minutes. However, CAPL considers these results to be untrustworthy as the TAPM-GRS model used in the 2008 SKM modelling studies is known to have limitations in modelling high exit velocity, dense gas releases, such as the acid gas exiting the AGRU vents. Furthermore, the acid gas venting scenario modelled involved continuous simultaneous acid gas venting from all three AGRUs at the maximum expected acid gas removal rates each day for 365 days a year, which is not expected to occur during the life of the Gorgon Gas Development.

Note: O_3 and BTEX were not specifically modelled for comparison against the National Occupational Health Exposure Standards during the 2008 SKM studies. Therefore, in light of the modelling results (e.g. the conservative O_3 results outlined in Section 5.2.2.6), and following feedback received from the DEC during the initial review process for this Plan (Ref. 52), CAPL undertook additional modelling for O_3, BTEX, and H_2S to further improve the accuracy of predicted ground-level concentrations for these pollutants. This modelling work is outlined in Sections 5.3 and 5.4, and detailed discussion on the modelling results is provided in Section 6.

5.2.2.9 Modelling Results for Deposition on Vegetation

The 2008 SKM modelling results for deposition on vegetation included estimates of dry deposition of SO_2 and NO_2 for the region surrounding Barrow Island, incorporating all emissions associated with the proposed GTP as well as existing and approved future sources.

The modelling results for SO_2 deposition associated with the existing and approved future sources indicated that higher deposition occurs over the sea, due to the high solubility of SO_2. The highest predicted SO_2 deposition occurred north-east of Barrow Island, reaching a maximum 0.02 kg/ha/year.

The modelling results for SO_2 deposition associated with the introduction of the GTP during routine operations predicted results for SO_2 deposition in the region around Barrow Island of 0.16 kg/ha/year, which is well below the WHO guideline value of eight to 16 kg/ha/year.

The modelling results for NO_2 deposition associated with the existing and approved future sources indicated that higher deposition occurs towards the centre of Barrow Island, with the predicted NO_2 deposition reaching a maximum 0.34 kg/ha/year.

The modelling results for NO_2 deposition associated with the introduction of the GTP during routine operations predicted results for NO_2 deposition of 0.61 kg/ha/year, which is well below the WHO guideline value of 15 to 20 kg/ha/year for lowland dry heathland.

A detailed discussion on the modelling results is provided in Section 6.

5.3 SKM Air Quality Modelling Studies 2010

5.3.1 TAPM-CTM Air Quality Modelling

CAPL commissioned SKM to conduct a TAPM modelling study (Ref. 39) in light of:

- the conservative modelling results associated with the non-routine cold start-up scenario and acid gas venting scenario (as outlined in Sections 5.2.2.4 and 5.2.2.6)
- feedback received from the DEC during the initial review process for this Plan (Ref. 52)
- subsequent design changes since the 2008 SKM modelling studies (Ref. 38) were completed.

This study was used to better qualify the impacts on local ambient air quality and further informed the design of the ambient air quality monitoring program outlined in Section 9.

This additional modelling work used the more advanced TAPM – Chemical Transport Model (TAPM-CTM), and included predictions of ambient concentrations of NO_2 and O_3 only.

A summary of the modelling results is presented in Sections 5.3.2.1 to 5.3.2.4, and detailed discussion on the modelling results is provided in Section 6.

5.3.2 Summary of TAPM-CTM Air Quality Modelling Results

5.3.2.1 Model Comparisons

The standard version of TAPM uses the Generalised Reaction Set (GRS) photochemistry scheme, which is optimised for fast processing rather than for accuracy. GRS models a first-order linear relationship between total source VOC concentrations and O_3 formation. All VOCs are represented by one species ('Rsmog') with seven competing reactions.

In contrast, the TAPM-CTM model is based on the Carbon Bond IV (CB-IV) and Carbon Bond V (CB-V) reaction schemes, which include more species and, more importantly, incorporate more reactions.

The simplifications in TAPM-GRS are known to produce an over-prediction in the rate of conversion of NO to NO_2. With the progress in photochemical modelling technology represented by TAPM-CTM, as well as the availability of faster computing hardware, TAPM-GRS is now used as a screening model to assess whether ambient concentrations may be expected to approach or exceed assessment criteria. If that turns out to be the case, then a more sophisticated model such as TAPM-CTM should be used to refine model predictions and improve their accuracy.

Therefore, the objectives of the additional TAPM-CTM study was to improve the accuracy of predicted ground-level concentrations of O_3 and NO_2 by refining the assumptions made in the 2008 SKM modelling studies, and included:

- refining estimates of background reactive organic compounds (Rsmog) previously used in the 2008 SKM modelling studies and conducting sensitivity analyses to examine the impact of the previously assumed Rsmog levels on modelling results for O_3
- modelling using TAPM-CTM to re-examine the maximum O_3 concentrations predicted in the 2008 SKM modelling studies
- modelling using TAPM-CTM to re-examine the maximum NO_2 concentrations predicted in the 2008 SKM modelling studies.

5.3.2.2 Results of Sensitivity Testing of TAPM Reactivity Inputs

The 2008 SKM modelling studies used Rsmog values of 0.2 ppb, which implied higher background VOCs than clean air, corresponding to an urban reactivity conversion coefficient of 0.0067 ppb.

As part of the 2010 studies, CSIRO's Division of Energy Technology provided estimates and confirmation of Rsmog values for both background air concentrations and industrial source emission rates, which showed that background Rsmog concentrations for Barrow Island were expected to be approximately 0.1 ppb, and 0.003 ppb for marine air (Ref. 39).

Sensitivity tests using the TAPM-GRS air quality model showed only small changes in predicted maximum concentrations when the background Rsmog concentration was reduced from 0.2 ppb to 0.1 ppb. Predicted maximum ground-level concentrations of O_3 were reduced from 272 µg/m^3 to 262 µg/m^3. Maximum O_3 concentrations across the modelling grid were reduced by approximately 20 µg/m^3 (see Figure 5-3; note that positive values across the grid indicate the scale of reduction in predicted ambient ground levels).

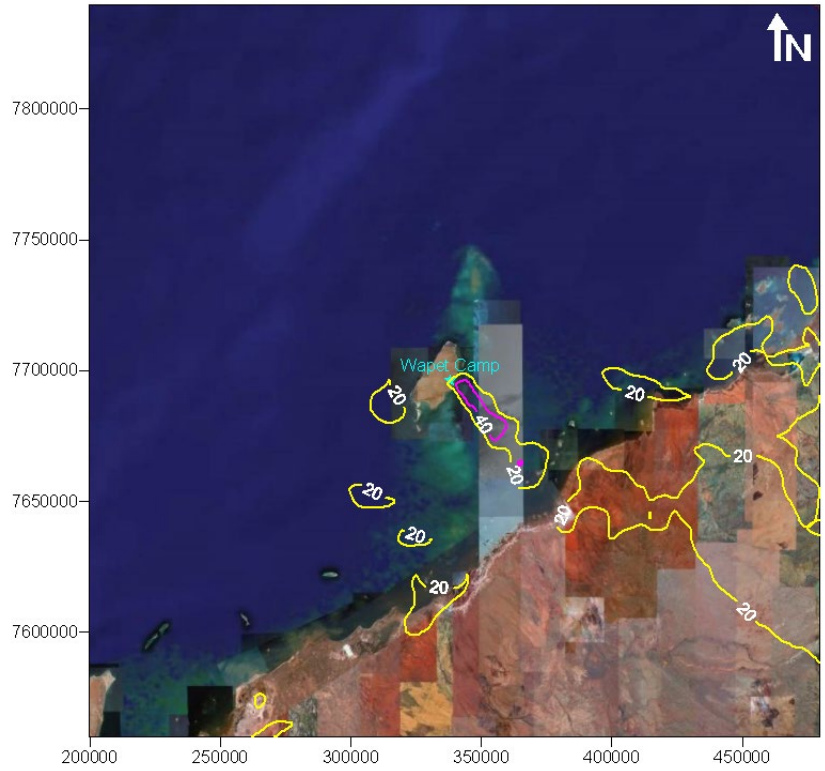


Figure 5-3: Predicted Reduction in Maximum One-hour Average Ground-level Concentrations (µg/m³) of Ozone after Reduction of Background Rsmog

CSIRO also provided improved estimates of Rsmog emissions factors. These showed that Rsmog emissions from the AGRU were overestimated during the 2008 SKM modelling studies, and thus the predicted maximum ambient ground-level O_3 concentrations were also overestimated.

Revised Rsmog emission rates from other sources in the GTP were the same or similar in magnitude to those modelled previously. Revised Rsmog emission factors led to a reduction in the AGRU Rsmog emission rate from 0.75 g/s to 0.21 g/s, which yielded a significantly lower predicted maximum ground-level O_3 concentration of 89 µg/m^3.

A sensitivity test was also run to evaluate changes to predicted ground-level concentrations of O_3 due to changes in the version of TAPM-GRS model used (e.g. using the latest version of the model with the same emissions input data and Rsmog values as the 2008 SKM modelling studies). The modelling results showed that there was a marginal reduction in O_3 concentrations in the vicinity of the GTP of about 10 µg/m^3, but an increase over most of the modelling domain of about 20 µg/m^3 (see Figure 5-4).

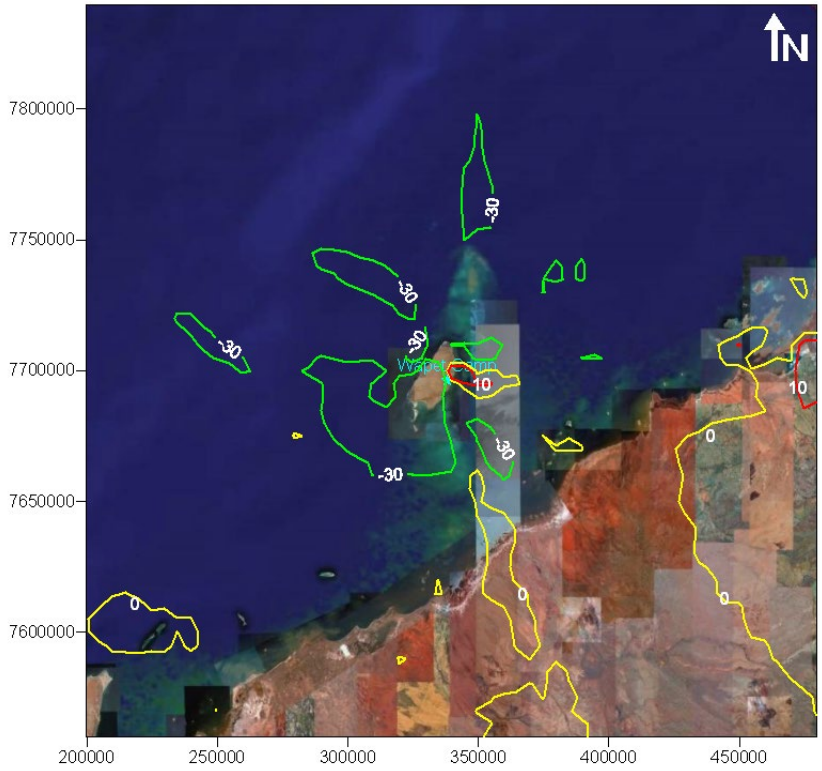


Figure 5-4: Predicted Changes in Maximum One-hour Average Ground-level Concentrations (µg/m³) of Ozone using Latest Version of TAPM-GRS

5.3.2.3 TAPM-CTM Model Input

Routine operations were modelled as the 'base case' using the following operational status of the major atmospheric pollutant emissions sources:

- all five Frame 9 GTGs operating
- all six Frame 7 GTs operating
- two Heating Medium Heaters maintained on hot stand-by
- Wet and Dry flares operating in non-routine flaring mode
- no acid gas venting at the AGRU trains; all acid gas injected
- concurrent condensate loading operations.

In addition to the above 'base case', two other cases were modelled—with one AGRU venting, and one with three AGRUs venting.

The Dry and Wet flares were modelled as ground flares, i.e. pollutants were modelled to be emitted from a circular area equivalent to the actual area of the flare on the plot plan. The most significant change in flare emissions characteristics compared to the 2008 SKM modelling study is the increased buoyancy of the flare exhaust plume due to the effect of a large area point source release.

Condensate loading operations were also modelled as continuous venting operations, although condensate offloading is expected to occur at an average

frequency of one condensate offtake per month, associated with approximately eight hours of condensate vapour venting at the offtake tanker's vent.

Note: The 2010 study did not include emissions from other existing and approved sources in the Pilbara Region.

5.3.2.4 Summary of TAPM-CTM Modelled Air Quality Results

The air quality modelling results for the maximum predicted ground-level concentrations of O_3 and NO_2 for the modelled scenarios are summarised in Table 5-18 and Table 5-19.

Table 5-18: Maximum Predicted O_3 Concentrations

		Maximum Predicted O_3 Concentrations			Assessment Criteria (Table 2-1)
		Base Case	Base Case plus 1 AGRU	Base Case plus 3 AGRUs	
One-hour Averaging Period	Maximum on Grid (µg/m^3)	140	147	167	214
	Percentage of Criteria (%)	65%	69%	78%	214
Four-hour Averaging Period	Maximum on Grid (µg/m^3)	119	119	125	171
	Percentage of Criteria (%)	70%	70%	70%	171

Source: Ref. 39

Note: The maximum predicted one-hour O_3 concentration for the base case occurs on Barrow Island, approximately 9 km west-south-west of the GTP. The maximum predicted one-hour O_3 concentration for the other modelled scenarios also occurs on Barrow Island, approximately 1.5 km east-south-east of the GTP.

The maximum predicted four-hour O_3 concentration for the base case occurs on Barrow Island, approximately 8 km west of the GTP. The maximum predicted four-hour O_3 concentration for the other modelled scenarios occurs approximately 1 km offshore Barrow Island (approximately 5 km east-north-east of the GTP).

In terms of ambient O_3 ground-level concentrations due to GTP operations on Barrow Island, the results indicate that local ambient air quality is expected to be acceptable because the results for the range of probable operating scenarios modelled are below the NEPM criteria. This conclusion is based on the assumption that other industrial sources in the Pilbara Region do not have a discernible impact on the ambient O_3 concentrations over Barrow Island.

Table 5-19: Maximum Predicted One-hour NO_2 Concentrations for the Base Case

Averaging Period	Maximum Predicted NO_2 Concentration (µg/m^3)	Assessment Criteria (µg/m^3) (Table 2-1)
One-hour	20	246

Source: Ref. 39

The maximum predicted one-hour NO_2 concentration of 20 µg/m^3 occurred at the southern end of Barrow Island, and is below the NEPM criteria. This is much lower

than the maximum predicted one-hour NO_2 concentration from the 2008 SKM modelling studies that used TAPM-GRS, and primarily is a direct consequence of the greater buoyancy of the flare emissions.

A detailed discussion on the modelling results is provided in Section 6.

5.4 ETC Air Quality Modelling Studies 2010

5.4.1 Acid Gas Dispersion Modelling

Chevron Energy Technology Company (ETC) were commissioned to conduct acid gas dispersion modelling to predict ambient air quality concentrations of both BTEX and H_2S at specified sensitive receptor locations on Barrow Island. This was required to:

- assess whether air quality will meet the appropriate ambient air quality standards and standards for human health in the workplace for personnel working on Barrow Island
- ensure that air pollutant and air toxic emissions from the GTP do not pose a risk of Material or Serious Environmental Harm to the flora, vegetation communities, terrestrial fauna, and subterranean fauna of Barrow Island
- further inform the design of the ambient air quality monitoring program outlined in Section 9.

This additional modelling was deemed necessary in light of the conservative modelling results associated with the non-routine acid gas venting scenario (as outlined in Section 5.2.2.6) and feedback received from the DEC during the initial review process for this Plan (Ref. 52).

A summary of the modelling results is presented in Section 5.4.2, and detailed discussion on the modelling results is provided in Section 6.

As previously noted, the results of the 2010 ETC modelling study were used as a basis for the:

- screening-level HRA (Ref. 40), which was undertaken to evaluate potential human health risks specifically associated with acid gas venting (as outlined in Section 6.2.6)
- screening-level terrestrial and marine ERAs (Ref. 49; Ref. 50), which were undertaken to assess potential environmental impacts to terrestrial and marine flora and fauna (as outlined in Section 6.2.7).

5.4.2 Summary of ETC Acid Gas Dispersion Modelling Results

5.4.2.1 Model Type

The dispersion model used by ETC in the study was Canary. Canary is a proprietary model that Chevron Corporation licenses from Quest Consultants; it comprises sophisticated, state-of-the-art thermodynamics, fluid dynamics, and dispersion sub-models, which are all based on peer-reviewed, public domain technical information available in the literature.

Canary is a comprehensive computer package that has algorithms to account for the following behaviours in simulating a release:

- the release rate
- the liquid-vapour flash

- any liquid pool formation and vaporisation
- aerosol formation and evaporation
- momentum-jet dispersion
- dense-cloud dispersion
- passive or neutral density dispersion (Gaussian).

As the release scenarios from the AGRU vents are all high exit velocity releases, the Canary model was chosen as the most appropriate model to use, as it has a momentum-jet routine, and the model can handle multicomponent releases, such as CO_2 mixed with H_2S and BTEX.

5.4.2.2 Model Input

Several acid gas venting scenarios were identified for the Gorgon Gas Development (Ref. 54). However, six were identified as either the most likely to occur frequently occurring, or most onerous in terms of acid gas venting rates, or both, and as such, were used in the modelling. These included:

- CO_2 compressor unavailability due to planned maintenance or a process trip condition (venting from Vent 1 – see Figure 5-2)
- high back-pressure from CO_2 wells or single well unavailability due to well workover resulting in high suction pressure to the compressor (venting from Vent 1)
- high back-pressure from CO_2 wells resulting in high suction pressure to the compressor, with unavailability of all four wells at a drill centre (venting from Vent 1)
- operating on Jansz gas only, until Gorgon gas is introduced (venting from Vent 1)
- CO_2 compressor venting during start-up to meet pipeline specifications (venting from Vent 3 – see Figure 5-2)
- MEG compressor trip (venting from Vent 6 – see Figure 5-2).

Each scenario involved different venting locations, under different release conditions, and at different release rates.

Figure 5-5 maps the sensitive receptor locations on Barrow Island that were considered during the ETC modelling study. Of these, eight were selected for comparison of the modelling results:

- Chevron Camp
- Butler Park
- GTP
- Permanent Operations Facility
- Terminal Tanks Site
- Jetty
- MOF
- WA Oil Base.

For the Chevron Camp and Butler Park, residential health risk criteria were taken into account when comparing the maximum predicted ground-level concentrations from the dispersion modelling. As noted in Section 2.3.1, the impact assessment criteria from the NSW DEC's Approved Methods for Modelling and Assessment of Air Pollutants in New South Wales (Ref. 31) were used (see Table 2-4). CAPL's use of this guidance document was based on advice received from the Industry Regulation Branch (Ref. 32). These criteria were taken into account when assessing general, non-occupational health exposure effects from BTEX on the workforce on Barrow Island.

For the other sensitive receptor locations where personnel perform work functions, occupational health exposure criteria were taken into account when comparing the maximum predicted ground-level concentrations from the dispersion modelling. For BTEX, the National Occupational Health Exposure Standards (Ref. 26) were used. However, for H_2S, an internal Chevron occupational health exposure standard was used as this was considered more stringent than the relevant National Occupational Health Exposure Standards.

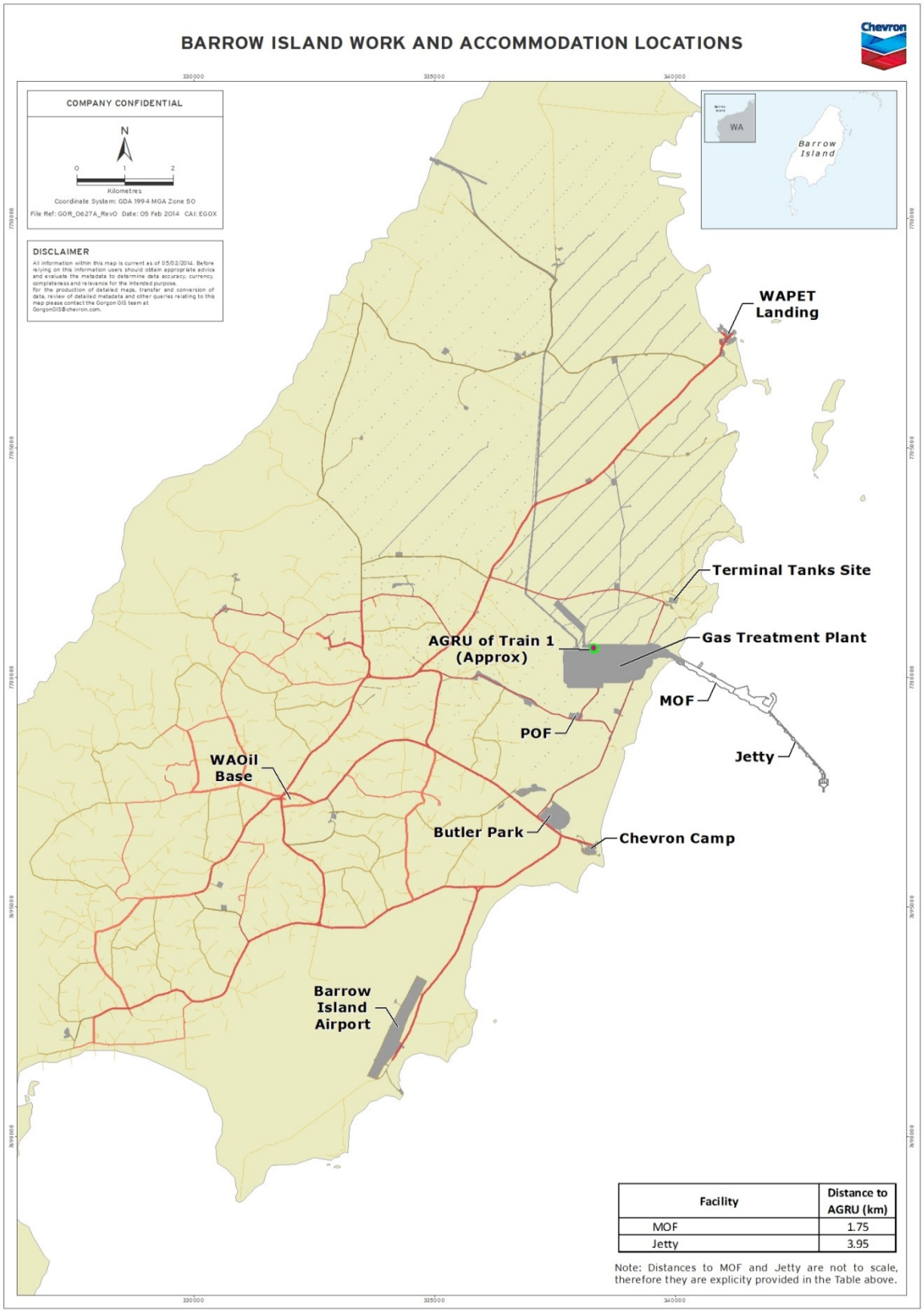


Figure 5-5: Barrow Island Sensitive Receptor Locations

5.4.2.3 Acid Gas Dispersion Modelling Results

The six scenarios described in Section 5.4.2.2 were modelled for the eight sensitive receptor locations listed in Section 5.4.2.2, using 24 combinations of wind weather stability conditions. These combinations were derived from the meteorological data file used in the 2008 SKM modelling studies (Ref. 38).

The dispersion modelling results for the maximum predicted ground-level concentrations during acid gas venting are summarised in Table 5-20 and Table 5-21.

Table 5-20: Maximum Predicted Atmospheric Pollutant Concentrations (Acid Gas Venting) – Residential Criteria

Pollutant	Averaging Period	Maximum Ground-level Concentrations (ppb)		Assessment Criteria (ppb) (Table 2-4)
		Butler Park	Chevron Camp	
Benzene	1 hour	1	<1	9
Toluene	1 hour	2	1	90
Ethylbenzene	1 hour	<1	<1	1800
Xylene	1 hour	<1	<1	40
H_2S	Peak concentration	<1	<1	1.0 – 3.5[1]

Source: Ref. 47

Note:

1. *As noted in the NSW DEC's Approved Methods for Modelling and Assessment of Air Pollutants in New South Wales (Ref. 31), the impact assessment criterion for H_2S varies with population size (e.g. 2 people – 3.5 ppb; 10 people – 3.0 ppb; ~30 people – 2.5 ppb; ~125 people – 2 ppb; ~500 people – 1.5 ppb; >2000 people – 1.0 ppb).*

Table 5-21: Maximum Predicted Atmospheric Pollutant Concentrations (Acid Gas Venting) – Occupational Criteria

Pollutant	Maximum Ground-level Concentrations (ppb)						Assessment Criteria – TWA[1] (ppb) (Table 2-3)
	GTP	Permanent Operations Facility	MOF	Terminal Tanks Site	Jetty	WA Oil Base	
Benzene	89	8	5	4	<1	<1	1000
Toluene	120	15	9.5	8	1	<1	100 000
Ethylbenzene	6	<1	<1	<1	<1	<1	100 000
Xylene	50	3	2	1	<1	<1	80 000
H_2S	28	6	4	3	<1	<1	5000

Source: Ref. 47

Note:

1. *The TWA concentration is measured over a normal eight-hour work day and a 40-hour work week, and is the concentration of an atmospheric contaminant to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.*

The dispersion modelling results summarised in Table 5-20 and Table 5-21 indicate that the predicted concentrations of H_2S and BTEX at the selected sensitive receptor locations are all below the relevant residential assessment criteria. For those receptors that were assessed against occupational health-

based assessment criteria, the maximum predicted ground-level concentrations are less than two orders-of-magnitude than the applicable assessment criteria.

5.5 Air Assessments Air Quality Modelling Study 2014

5.5.1 Mercury Dispersion and Deposition Modelling

Air Assessments were commissioned to conduct dispersion and deposition modelling to predict ambient air quality concentrations and deposition rates for Hg at specified sensitive receptor locations on Barrow Island (Ref. 41). The objectives of this assessment were to:

- assess whether air quality will meet appropriate ambient air quality standards and standards for human health in the workplace for personnel working on Barrow Island
- ensure Hg emissions from the GTP do not pose a risk of Material or Serious Environmental Harm to the flora, vegetation communities, terrestrial fauna, and subterranean fauna of Barrow Island
- further inform the design of the ambient air quality monitoring program outlined in Section 9.

This additional modelling was deemed necessary in light of improvements in Hg sampling and testing methods, which resulted in higher Hg concentrations being detected in the feed gas than previously predicted. Although the higher Hg concentrations are considered minor, they exceed the previous basis of design for the GTP, and additional Hg management was determined to be necessary.

A summary of the completed modelling is presented in Section 5.5.2, and detailed discussion on the modelling results is provided in Section 6.

5.5.2 Summary of Air Assessments Modelling Results

5.5.2.1 Model Type

The dispersion model used by Air Assessments in the study was CALPUFF. CALPUFF was selected because of its ability to model dispersion and deposition over land and water and its ability to model low wind speed meandering, which is important for surface sources of Hg at distances greater than several kilometres.

5.5.2.2 Model Input

Several emission scenarios were identified for the Gorgon Gas Development that were anticipated to contain very low levels of Hg. Four of these scenarios were identified as either the most frequently occurring or the most onerous in terms of Hg venting rates, or both, thus these were used in the modelling.

Routine operations were modelled as the ‘base case’, which is anticipated to occur up to 95% of the time, using the following operational status of the major atmospheric pollutant emissions sources:

- all five Frame 9 GTGs operating
- all six Frame 7 GTs operating
- two Heating Medium Heaters maintained on cold stand-by
- Wet and Dry flares operating on pilot and purge fuel gas only; no non-routine flaring

- BOG flares operating on pilot and purge fuel gas only; no non-routine flaring
- no acid gas venting at the AGRU trains; all acid gas injected
- minor venting from the Gorgon and Jansz Rich MEG Tank vents.

Non-routine operations covered the remaining three scenarios outlined below, with these differing to the 'base case' as follows:

- acid gas venting – the worst-case non-routine operations scenario associated with the unavailability of the CO_2 Injection System, which is anticipated to occur for 5% of the time (however, this was modelled conservatively as 20% of the time), resulting in venting of MEG flash vapour via the MEG Flash Gas Compressor vent
- shutdown – anticipated to occur for less than one hour per year (or less than 0.011% of the time), using the following operational status of the major atmospheric pollutant emissions sources:
  - four Frame 9 GTGs operating
  - four Frame 7 GTs operating
  - one Heating Medium Heater on hot stand-by (pilot flame only); one maintained on cold stand-by
  - Wet and Dry flares operating (all four flare pits)
  - BOG flares operating on pilot and purge fuel gas only; no non-routine flaring
  - no acid gas venting at the AGRU trains; all acid gas injected
  - minor venting from the Gorgon and Jansz Rich MEG Tank vents
- cold start (i.e. black start) – anticipated to occur for fewer than six hours per year (or less than 0.07% of the time), using the following operational status of the major atmospheric pollutant emissions sources:
  - four Frame 9 GTGs operating
  - four Frame 7 GTs operating
  - one Heating Medium Heater operating at full design rate; one maintained on hot stand-by (pilot flame only)
  - Wet and Dry flares operating (all four flare pits)
  - BOG flares operating on pilot and purge fuel gas only; no non-routine flaring
  - no acid gas venting at the AGRU trains; all acid gas injected
  - plus minor venting from the Gorgon and Jansz Rich MEG Tank vents.

The key difference between the shutdown and cold start scenarios relates to flaring and Heating Medium Heater emission rates.

5.5.2.3 Mercury Speciation

The speciation of Hg used in the model was estimated by CAPL based on:

- combustion sources (including the Frame 9 GTGs, Frame 7 GTs, Heating Medium Heaters, and Flares), which were specified as 50% elemental, 30% divalent, and 20% particulate Hg using the USEPA default speciation

(Ref. 56). The USEPA provides profiles for a wide range of source categories that include:

- 50:30:20 split for process heaters and stationary gas turbines
- 80:10:10 split for flares
- sources not covered by the above being assigned the default profile of 50:30:20.

Based on this, the 50:30:20 split was considered most appropriate for combustion sources, being slightly more conservative for the flares as higher deposition would occur with higher emissions of divalent and particulate Hg.

- AGRU vents were specified as 100% elemental as this is a non-combusted source
- Gorgon and Jansz Rich MEG Tank emissions are also non-combusted and specified as 100% elemental Hg based on partitioning of the vapours in the tanks.

The breakdown of Hg emissions by source was:

- For routine operations, given the MRU engineering controls to be installed upstream of all major emissions sources, the Gorgon Rich MEG Tank vents were the largest source of Hg contributing 94.54%, with the Jansz Rich MEG Tank vents contributing 4.72% of total Hg emissions – all other stacks and vents contribute only 0.74% of total Hg emissions.
- For acid gas venting (the worst-case non-routine operations scenario), the MEG Flash Gas Compressor vent is the largest source of Hg contributing 98.83% of total Hg emissions—over an operating year, assuming a conservative 20% acid gas venting, the total Hg emissions would be approximately 35.2 kg/year (however, based on an anticipated 5% venting per annum this would be less than 10.2 kg/year).
- For shutdown and black-start conditions, total Hg emissions were similar to routine operations as Hg emissions from the largest source (i.e. Gorgon and Jansz Rich MEG Tanks) remain the same. For these two scenarios, there were increases in Hg emissions from the flares and Heating Medium Heaters; however, these were offset by reductions in Hg emissions from the Frame 9 GTGs and Frame 7 GTs.

It should be reiterated that total Hg emissions associated with the commissioning, start-up, and operation of the GTP are considered minor and are comparable to the range found in the industry (as shown in Table 1-4 in Section 1.6).

5.5.2.4 Sensitive Receptors

The sensitive receptor locations on Barrow Island that were considered for comparison against the modelling results include:

- Chevron Camp
- Butler Park
- GTP
- Permanent Operations Facility
- MOF

- Jetty Head
- WAPET Landing
- Terminal Tanks
- WA Oil Base
- Airport
- Old Airport (western end, middle, and eastern end).

For the Chevron Camp and Butler Park, residential health risk criteria were taken into account (see Section 2.3.3) to assess general, non-occupational type health exposure effects from Hg on the workforce on Barrow Island. For the other sensitive receptor locations where personnel work, occupational health exposure criteria were taken into account.

5.5.2.5 Mercury Dispersion Modelling Results

The dispersion modelling results for maximum predicted ground-level concentrations for Hg are summarised in Table 5-22 and Table 5-23.

Table 5-22: Maximum Predicted Mercury Concentrations – Routine Operations

Sensitive Receptor	Assessment Criteria (see Table 2-5 and Table 2-6, Section 2.3.3)	Averaging Period	Maximum Ground-level Concentrations[1,2] (ng/m^3) (Percentage of Criteria [%])	
			Routine Operations[3]	Routine Operations[3] (including Background Levels)[4]
Residential Criteria				
Chevron Camp	1800	1-hour[5]	0.68 (0.038%)	2.68 (0.15%)
	200	Annual	0.0055 (0.0055%)	1.256 (0.63%)
Butler Park	1800	1-hour[5]	0.9 (0.0021%)	2.9 (0.16%)
	200	Annual	0.009 (0.05%)	1.259 (0.63%)
Occupational Criteria				
GTP	25 000	8-hour	2.2 (0.0088%)	4.2 (0.017%)
Permanent Operations Facility			1.7 (0.0068%)	3.7 (0.015%)
MOF			0.5 (0.002%)	2.5 (0.01%)
Terminal Tanks Site			0.65 (0.0026%)	2.65 (0.011%)
Jetty Head			0.23 (0.0009%)	2.23 (0.0089%)

Sensitive Receptor	Assessment Criteria (see Table 2-5 and Table 2-6, Section 2.3.3)	Averaging Period	Maximum Ground-level Concentrations[1,2] (ng/m³) (Percentage of Criteria [%])	
			Routine Operations[3]	Routine Operations[3] (including Background Levels)[4]
WA Oil Base			0.18 (0.0007%)	2.18 (0.0087%)

Source: Ref. 41

Notes:

1. *Concentrations and assessment criteria are presented in ng/m³ to aid in presentation of results, as the predicted ground-level concentrations are very low.*
2. *Concentrations are the total of elemental Hg, divalent, Hg and particulate Hg. More than 99% of the Hg emissions are associated with elemental Hg.*
3. *Routine operations do not include any CO_2 venting.*
4. *Background Hg levels are determined based on global emissions and primarily comprise elemental Hg. For the region near Barrow Island, anthropogenic sources should be minimal, with the largest local sources being emissions from soils, vegetation, and fires. Estimates of background levels across Australia were presented in a modelling study that included all known sources, including industrial emissions and natural sources (Ref. 48). Annual predictions from this study indicate that for a location near Onslow a typical value is 1.25 ng/m³; with a shorter-term peak concentration of 2 ng/m³ considered reasonable (Ref. 41).*
5. *The 1-hour criteria is the 99.9th percentile.*

Table 5-23: Maximum Predicted Mercury Concentrations – Non-Routine Operations

Sensitive Receptor	Assessment Criteria (see Table 2-5 and Table 2-6, Section 2.3.3)	Averaging Period	Maximum Ground-level Concentrations[1,2,6] (ng/m³) (Percentage of Criteria [%])	
			Non-Routine Operations with 20% CO_2 Venting[3]	Non-Routine Operations with 20% CO_2 Venting[3] (including Background Levels)[4]
Residential				
Chevron Camp	1800	1-hour[5]	21 (1.2%)	23 (1.3%)
	200	Annual	0.04 (0.02%)	1.29 (0.65%)
Butler Park	1800	1-hour[5]	34 (1.9%)	36 (2.0%)
	200	Annual	0.08 (0.04%)	1.33 (0.67%)
Occupational Criteria				
GTP	25 000	8-hour	100 (0.4%)	102 (0.408%)
Permanent Operations Facility			35 (0.14%)	37 (0.148%)
MOF			15	17

Sensitive Receptor	Assessment Criteria (see Table 2-5 and Table 2-6, Section 2.3.3)	Averaging Period	Maximum Ground-level Concentrations[1,2,6] (ng/m^3) (Percentage of Criteria [%])	
			Non-Routine Operations with 20% CO_2 Venting[3]	Non-Routine Operations with 20% CO_2 Venting[3] (including Background Levels)[4]
			(0.06%)	(0.068%)
Terminal Tanks Site			38 (0.15%)	40 (0.16%)
Jetty Head			10 (0.04%)	12 (0.048%)
WA Oil Base			20 (0.08%)	22 (0.088%)

Source: Ref. 41

Notes:

1. *Concentrations and assessment criteria are presented in ng/m^3 to aid in presentation of results, as the predicted ground-level concentrations are very low.*
2. *Concentrations are the total of elemental Hg, divalent Hg, and particulate Hg. More than 99% of the Hg emissions are associated with elemental Hg.*
3. *Non-routine operations include 20% CO_2 venting (as a conservative estimate). To provide worst-case estimates of the 1-hour and 8-hour Hg concentrations, predictions were obtained from the model run assuming CO_2 venting occurs for every hour over a 3-year period. This ensured CO_2 venting would occur at the time of worst-case dispersion. The annual average concentration is based on 80% of the non-CO_2 venting model run and 20% of the result from the model run with CO_2 venting.*
4. *Background Hg levels are determined based on global emissions and primarily comprise elemental Hg. For the region near Barrow Island, anthropogenic sources should be minimal, with the largest local sources being emissions from soils, vegetation, and fires. Estimates of background levels across Australia were presented in a modelling study that included all known sources, including industrial emissions and natural sources (Ref. 48). Annual predictions from this study indicate that for a location near Onslow a typical value is 1.25 ng/m^3; with a shorter-term peak concentration of 2 ng/m^3 considered reasonable (Ref. 41).*
5. *The 1-hour criteria is the 99.9th percentile.*
6. *Non-routine shutdown and black-start conditions were also modelled; however, maximum ground-level concentrations at any grid point increased by a maximum of 0.10% from the modelled routine operations case, therefore, these results were not included.*

The dispersion modelling results summarised in Table 5-22 and Table 5-23 indicate that the predicted concentrations of Hg at the selected sensitive receptor locations are all well below the relevant residential and occupational health assessment criteria.

Predicted concentrations during routine operations (not including background levels) were at most 0.05% of the relevant residential criteria at the accommodation areas, and at most 0.0088% of the relevant occupational health-based criteria at the other sensitive receptor locations.

Predicted concentrations were observed to decrease rapidly with distance from the GTP as the largest source of Hg is the Gorgon and Jansz Rich MEG Tank vents. Such low-level emission sources typically result in the highest concentrations under light wind, stable conditions and decrease rapidly with distance from the source.

The highest predicted concentrations during non-routine operations (not including background levels) occur during acid gas venting (which was conservatively assumed to occur 20% of the time annually), and were at most 1.9% of the

relevant residential criteria at the accommodation areas, and at most 0.4% of the relevant occupational health-based criteria at the other sensitive receptor locations.

Predicted concentrations increase slightly when taking into account background levels (which have a greater impact on ambient air quality than emissions from the GTP), and were at most 2.0% of the relevant residential criteria at the accommodation areas, and at most 0.41% of the relevant occupational health-based criteria at the other sensitive receptor locations, during acid gas venting.

Non-routine shutdown and black-start conditions were also modelled; however, maximum ground-level concentrations at any grid point increased by a maximum of 0.10% during a shutdown from the modelled routine operations case, thus, these results were not included in Table 5-23.

5.5.2.6 Mercury Deposition Modelling Results

Deposition modelling was undertaken to predict deposition rates for Hg at specified sensitive receptor locations on Barrow Island.

During routine operations, the modelling indicated a rapid decrease in deposition rates with distance from the GTP, with a maximum annual Hg deposition rate of 25 µg/m^2/year at the GTP and 0.08 µg/m^2/year at the accommodation areas. Gaseous elemental Hg is the major contributor and dry gaseous deposition is the major pathway, with the Gorgon and Jansz Rich MEG Tank vents being the main source.

For Hg deposition at the accommodation areas, the deposition rate of 0.08 µg/m^2/year will only add approximately 4% to the existing background deposition rate of ~2.6 µg/m^2/year (e.g. 2.5 µg/m^2/year dry deposition and 0.1 µg/m^2/year wet deposition). Predicted deposition rates will exceed the natural (low) deposition rates only within approximately 200–400 m of the Gorgon and Jansz Rich MEG Tank vents.

During non-routine operations, the modelling predicted a rapid decrease in deposition rates with distance from the GTP, with a maximum annual Hg deposition rate of 55 µg/m^2/year at the GTP and 0.65 µg/m^2/year at the accommodation areas. Again, gaseous elemental Hg is the major contributor and dry gaseous deposition is the major pathway, with the MEG Flash Gas Compressor vent the main source.

For Hg deposition at the accommodation areas, the deposition rate of 0.65 µg/m^2/year will add approximately 25% to the existing background deposition rate of ~2.6 µg/m^2/year (e.g. 2.5 µg/m^2/year dry deposition and 0.1 µg/m^2/year wet deposition).

Note: The above deposition rates are considered overestimates of actual net deposition as the model does not take into account resuspension or re-emission of volatile elemental Hg, which can be greater than 50% and is typically enhanced by dry and hot climates such as experienced on Barrow Island.

Deposition rates during non-routine shutdown and black-start conditions are even smaller, as shutdowns and black starts are anticipated for a very small percentage of the time (at most 0.011% and 0.07 % in a year respectively). Therefore, the change in annual deposition rates from the routine operations case is negligible.

6 Assessment of Modelling Results

6.1 Introduction

As outlined in Section 5, CAPL has conducted several air quality modelling studies to assess potential impacts from atmospheric pollutants and air toxic emissions on the local and regional air quality as a result of the operation of the GTP.

The conclusions drawn from the assessment of the modelling results for both the commissioning and start-up phase and operations phase, are outlined in Sections 6.2 and 6.3. Assessment of modelling results for the temporary flaring of MEG flash vapour is provided in Section 6.4.3.

6.2 Operations Phase

6.2.1 Comparison to National Ambient Air Quality Standards

6.2.1.1 Routine Operations

The 2008 SKM modelling studies (Ref. 38) showed that during routine operations concentrations of NO_2 and O_3 are predicted to increase marginally compared to the modelled background air quality results, with the maximum predicted concentrations remaining well below the relevant NEPM ambient air quality criteria.

The largest increase in any atmospheric pollutant in the ambient air environment during routine operations was for SO_2, which is directly linked to the increase in SO_2 emissions associated with emission sources located within the GTP; however, the maximum predicted concentrations remain well below the relevant NEPM ambient air quality criteria.

The maximum predicted PM_{10} concentrations during routine operations are less than 2% of the relevant NEPM criteria. As background PM_{10} concentrations were not modelled, it is not possible to assess any increase in PM_{10} in the ambient environment during routine operations; however, any potential impacts associated with an increase in PM_{10} are considered negligible.

The primary source of BTEX and H_2S from operation of the GTP is from acid gas venting events. As acid gas venting is a non-routine operating scenario, ambient concentrations of BTEX and H_2S during routine operations are expected to be at or close to background levels across Barrow Island.

Based on these modelling results, during routine operations ground-level concentrations of atmospheric pollutants and air toxic emissions are estimated to remain below the relevant NEPM ambient air quality criteria. Therefore, ambient air quality is expected to be acceptable (i.e. meets appropriate standards for human health in the workplace and does not pose a risk of Material or Serious Environmental Harm to the flora, vegetation communities, terrestrial fauna, and subterranean fauna of Barrow Island).

Furthermore, routine operating conditions, and thereby the associated local and regional air quality, are expected to prevail for more than 80% of the operating time of the GTP (expressed as a five-year rolling average) during the initial years of operation, and up to 95% of the operating time following year six of GTP operations (Ref. 53).

6.2.1.2 Non-routine Operations – Cold Start-up

The 2008 SKM modelling studies (Ref. 38) showed that during a cold start-up (e.g. cold restart of an LNG Train), concentrations of SO_2, PM_{10}, and O_3 were all below the relevant NEPM ambient air quality criteria.

The largest increase in any atmospheric pollutant in the ambient air environment during a cold start-up was for NO_2 emissions associated with Wet gas flaring. The associated modelling results predicted a maximum one-hour NO_2 concentration of 341 µg/m^3, or 139% of the relevant NEPM ambient air quality criteria, with this maximum ground-level concentration occurring immediately north-east of the GTP. The cause of this high concentration is attributed to the high NO_2 emissions associated with approximately 30% of the normal flow rate of a single LNG train being directed to the Wet flare as the LNG is brought to specification.

However, analysis of the output file from the 2008 SKM modelling studies indicated that this high concentration only occurs for one hour and that the second highest concentration is only 72% of the NEPM ambient air quality criteria. More importantly, the predicted maximum NO_2 concentration at the Chevron Camp and Butler Park is predicted to be only 33.3% of the relevant NEPM ambient air quality criteria.

As noted in Section 5.2.2.4, in light of these modelling results additional modelling was undertaken to further improve the accuracy of predicted NO_2 ground-level concentrations during a cold start-up (specifically, a non-routine flaring event).

The 2010 SKM modelling study (Ref. 39) showed that maximum predicted one-hour NO_2 concentrations during a non-routine flaring event would be low (i.e. 20 µg/m^3, or approximately 8% of the relevant NEPM ambient air quality criteria). This reduction in maximum predicted one-hour NO_2 concentrations is attributed to using a different modelling approach for the wet flares; specifically, it is a direct consequence of using a greater buoyancy for the flare emissions (i.e. modelling the flares as ground flares and consequently an area rather than a point source emission).

Based on these modelling results, ground-level concentrations of atmospheric pollutants and air toxic emissions during a cold start-up are estimated to remain below the relevant NEPM ambient air quality criteria, and therefore, ambient air quality is expected to be acceptable.

6.2.1.3 Non-routine Operations – Emergency Shutdown

The 2008 SKM modelling studies (Ref. 38) showed that during an emergency shutdown of the GTP, the ground-level concentrations of atmospheric pollutants and air toxic emissions are estimated to remain below the relevant NEPM ambient air quality criteria, and therefore ambient air quality is expected to be acceptable.

Furthermore, the 2010 SKM modelling study (Ref. 39) confirmed that during a non-routine flaring event, maximum predicted one-hour NO_2 concentrations are estimated to remain below the relevant NEPM ambient air quality criteria.

6.2.1.4 Non-routine Operations – Acid Gas Venting

The 2008 SKM modelling studies (Ref. 38) showed that during acid gas venting, the ground-level concentrations of NO_2, SO_2, and PM_{10} are estimated to remain below the relevant NEPM ambient air quality criteria.

The acid gas venting scenario modelled involved continuous acid gas venting from all three AGRUs at the maximum expected acid gas removal rates each day

for 365 days a year, which is not expected to occur during the life of the Gorgon Gas Development. This scenario resulted in a maximum predicted one-hour concentration of O_3 of 272 µg/m^3, which is equivalent to 127% of the applicable NEPM criteria. Of the top ten O_3 concentrations predicted to occur during this scenario, the highest and second highest concentrations were above the one-hour NEPM criterion, with all subsequent concentrations predicted to be below the one-hour NEPM criterion.

These modelling results also indicated that even with continuous acid gas venting at the GTP at maximum acid gas production rates over an entire year, the maximum predicted one-hour O_3 concentration at both the Chevron Camp and the Butler Park would be 200 µg/m^3, which is equivalent to 93.5% of the applicable NEPM criterion.

As this type of non-routine scenario is expected to occur at most once every five years and only for approximately five days, the potential for these high concentrations of O_3 in the ambient environment is considered to be very low.

However, in light of these conservative modelling results, CAPL undertook additional modelling for O_3 to further improve the accuracy of predicted ground-level concentrations.

The 2010 SKM modelling study (Ref. 39) used TAPM-CTM to further predict O_3 concentrations associated with acid gas venting. The results showed a significant reduction in the maximum one- and four-hour O_3 concentrations, with the maximum ground-level concentrations predicted to be less than the relevant NEPM ambient air quality criteria. This reduction in O_3 concentrations was directly attributed to use of the more sophisticated TAPM-CTM model.

In consideration of the SKM 2010 modelling results, together with the expected frequency of the most probable acid gas venting events, CAPL considers the predicted O_3 concentrations during periods of non-routine operations involving acid gas venting (even when combined with upset process flaring) are expected to comply with the relevant NEPM ambient air quality criteria.

As air toxics such as BTEX were not specifically modelled during the 2008 SKM modelling studies, the 2010 ETC modelling study looked specifically at predicting ambient air quality concentrations of BTEX (and H_2S) during acid gas venting at specified sensitive receptor locations on Barrow Island. The results showed that the maximum ground-level concentrations of BTEX remain below the relevant assessment criteria from the NSW DEC's Approved Methods for Modelling and Assessment of Air Pollutants in New South Wales (Ref. 31).

Based on the above modelling results, ground-level concentrations of atmospheric pollutants and air toxic emissions during acid gas venting are estimated to remain below the relevant assessment criteria, and therefore ambient air quality is expected to be acceptable.

6.2.1.5 Conclusion

As shown from the discussion of the modelling results presented in the above sections, ground-level concentrations of atmospheric pollutants and air toxic emissions for all scenarios modelled to date are estimated to remain below the relevant assessment criteria, and therefore ambient air quality is expected to be acceptable (i.e. meets appropriate standards for human health in the workplace and does not pose a risk of Material or Serious Environmental Harm to the flora, vegetation communities, terrestrial fauna, and subterranean fauna of Barrow Island).

6.2.2 Comparison to NEPM (Air Toxics) Monitoring Investigation Levels

The results of the 2010 ETC modelling study (as summarised in Table 5-20 and

Table 5-21) were used to calculate the annual average benzene, toluene, and xylene concentrations for comparison against the NEPM (Air Toxics) Monitoring Investigation Levels (see Table 2-2).

The results of these calculations are summarised in Table 6-1. The calculations were based on these assumptions:

- acid gas venting could occur at any time of the year, with the GTP assumed to operate uninterrupted throughout the whole year
- acid gas venting was estimated to occur for a total of 1325 hour in any typical calendar year, averaged over five years

each acid gas venting scenario was assumed to result in the modelled worst-case ground-level concentrations of air toxics outside the GTP (as summarised in

- Table 5-21), with the maximum ground-level concentrations at the Permanent Operations Facility used in the calculation
- for average annual concentrations at the Chevron Camp and Butler Park, the actual predicted ground-level concentrations at those locations were used in the calculation
- worst-case one-hour average xylene concentrations at Butler Park were assumed to be 1 ppb (modelled as less than 1 ppb in the 2010 ETC modelling study).

Table 6-1: Estimated Annual Atmospheric Pollutant Concentrations for Benzene, Toluene, and Xylene (Acid Gas Venting)

Pollutant	Annual Average Ground-level Concentrations (ppb)		Assessment Criteria (ppb) (Table 2-2)
	Worst-case (outside the GTP)	Residential Locations[1]	
Benzene	1.2	0.2	3
Toluene	2.3	0.3	100
Xylene	0.45	0.2	200

Note:

1. *The residential locations considered as part of the 2010 ETC modelling study included the Chevron Camp and Butler Park.*

The results in Table 6-1 indicate that the estimated annual average ground-level concentrations for air toxics are expected to be below the relevant NEPM (Air Toxics) Monitoring Investigation Levels.

As the worst-case one-hour average concentrations for toluene and xylene outside the GTP were estimated to be 15 ppb and 3 ppb respectively (see

Table 5-21), it is not expected that the daily average monitoring investigation levels for toluene and xylene of 1000 ppb and 250 ppb respectively (see Table 2-2) will be exceeded during the operation of the GTP.

Ground-level concentrations of benzene outside the GTP associated with acid gas venting from the Jansz field during the commissioning and start-up period were estimated at less than 1 ppb; therefore, the annual average concentration of

benzene is expected to be less than 1 ppb. The modelling results for toluene and xylene associated with acid gas venting during the commissioning and start-up period indicated a worst-case concentration outside the GTP of 2 ppb for both chemicals; therefore, an annual average concentration is expected to be below the relevant NEPM investigation level criteria.

6.2.3 Comparison to National Occupational Health Exposure Standards

The 2008 SKM modelling studies (Ref. 38) predicted that during routine and non-routine operations, the maximum ambient concentrations of NO_2, SO_2, and H_2S would remain below the relevant National Occupational Health Exposure Standards.

In addition, the 2010 ETC modelling study indicated that the predicted concentrations of BTEX and H2S at the selected sensitive receptor work locations within and outside the GTP were more than two orders-of-magnitude lower than the applicable occupational health criteria (refer to Table 5-12).

Thus it is considered that occupational health exposures at all work locations on Barrow Island, including those beyond the fence line of the GTP, are expected to comply with the relevant National Occupational Health Exposure Standards, as identified in Table 2-3.

6.2.4 Comparison to Non-occupational Health Exposure Criteria

As outlined in Section 2.3.1, the potential for low-level H_2S and BTEX concentrations to be present in the ambient air environment has necessitated the assessment of general, non-occupational type health exposure effects (e.g. impacts to human health from exposure outside working environments) to the workforce on Barrow Island, with such exposures potentially occurring following prolonged periods of acid gas venting.

The 2010 ETC modelling study indicated that the predicted average one-hour ground-level concentrations of BTEX and H_2S at the selected sensitive receptor locations, where people congregate outside their working hours on Barrow Island (i.e. the Chevron Camp and Butler Park), were below the relevant NSW DEC assessment criteria (Ref. 31).

As benzene is a recognised carcinogen and ethylbenzene is a probable carcinogen, the predicted ambient ground-level concentrations of these air toxics were used to conduct the HRA, and to assess whether emissions from the GTP operations have the potential to pose a risk of Material or Serious Environmental Harm to the workforce, flora, vegetation communities, terrestrial fauna, and subterranean fauna on Barrow Island.

6.2.5 Comparison to Mercury Criteria

6.2.5.1 Routine Operations

The 2014 Air Assessments modelling study (Ref. 41) showed that during routine operations, concentrations of Hg are predicted to increase marginally compared to the modelled background results, with the maximum predicted concentrations at the selected sensitive receptor locations all well below the relevant residential and occupational health assessment criteria.

Under routine operations, the primary source of Hg is from the Gorgon and Jansz Rich MEG Tank vents, which contribute 99.27% of total Hg emissions (primarily in the form of gaseous elemental Hg). Overall, 99.64% of total Hg emissions are

estimated to be elemental Hg, with total Hg emissions estimated at 1.85 kg per year.

Annual deposition rates are predicted to increase marginally compared to the modelled background results, with maximum deposition rates of approximately 25 µg/m^2/year at the GTP and approximately 0.08 µg/m^2/year at accommodation areas, with the major component being elemental Hg (with dry gaseous deposition being the major pathway). These estimates will overstate the net deposition rates as the model does not take into account re-emission.

Based on these modelling results, during routine operations ground-level concentrations of Hg emissions are estimated to remain below the relevant residential and occupational health assessment criteria. Therefore, it is expected that ambient air quality will be acceptable (i.e. meets appropriate standards for human health in the workplace and does not pose a risk of Material or Serious Environmental Harm to the flora, vegetation communities, terrestrial fauna, and subterranean fauna of Barrow Island).

Routine operating conditions, and thus the associated local and regional air quality, are expected to prevail for more than 80% of the operating time of the GTP (expressed as a five-year rolling average) during the initial years of operation, and up to 95% of the operating time following year six of GTP operations (Ref. 53).

6.2.5.2 Non-routine Operations

The 2014 Air Assessments modelling study (Ref. 41) showed that during non-routine operations, concentrations of Hg are predicted to increase marginally compared to the modelled background results, with the maximum predicted concentrations at the selected sensitive receptor locations occurring during acid gas venting; however, the predicted concentrations still remain well below the relevant residential and occupational health assessment criteria.

Under non-routine operations, the primary source of Hg is from the MEG Flash Gas Compressor vent, which is expected to contribute 98.83% of total Hg emissions; over an operating year, assuming a conservative 20% acid gas venting, the total Hg emissions would be approximately 35.2 kg/year (however, based on an anticipated 5% venting per year this would be less than 10.2 kg/year).

Annual deposition rates are predicted to increase marginally compared to the modelled background results, with maximum deposition rates of approximately 55 µg/m^2/year at the GTP and approximately 0.65 µg/m^2/year at accommodation areas, with the major component again being elemental Hg (with dry gaseous deposition being the major pathway). These estimates overstate the net deposition rates as the model does not take into account re-emission.

The 2019 Ramboll modelling study (Ref. 46) predicted ground level concentrations of Hg (assuming continuous venting from the MEG Flash Gas Compressor vent) would range from a 1-hour average of 1.16 µg/m^3 and annual average of 0.0457 µg/m^3 at the GTP to a 1-hour average of 0.249 µg/m^3 and annual average of 0.0007 µg/m^3 at the Butler Park accommodation facility. Flaring of the MEG flash gas would reduce the 1-hour average ground-level concentration of Hg to 0.0101 µg/m^3 (versus the occupational criteria of 25 µg/m^3) and to 0.009 µg/m^3 at Butler Park (versus the residential criteria of 1.8 µg/m^3). Annual ground-level concentrations of Hg were similarly reduced by flaring at all the locations modelled.

Based on these modelling results, during non-routine operations ground-level concentrations of Hg emissions are estimated to remain below the relevant residential and occupational health assessment criteria. Therefore, it is expected that ambient air quality will be acceptable (i.e. meets appropriate standards for human health in the workplace and does not pose a risk of Material or Serious Environmental Harm to the flora, vegetation communities, terrestrial fauna, and subterranean fauna of Barrow Island).

6.2.5.3 Conclusion

Ground-level concentrations of Hg for all scenarios modelled are estimated to remain below the relevant assessment criteria, and therefore ambient air quality is expected to be acceptable (i.e. meets appropriate standards for human health in the workplace and does not pose a risk of Material or Serious Environmental Harm to the flora, vegetation communities, terrestrial fauna, and subterranean fauna of Barrow Island).

6.2.6 2010 Screening-level Health Risk Assessment

A screening-level HRA was performed by an ETC human health toxicologist (Ref. 40) to evaluate potential human health risks associated with various acid gas venting scenarios, as modelled in the 2010 ETC modelling study Ref. 47).

The risk assessment methodology was in accordance with these HRA guidance documents:

- Environmental Health Risk Assessment: Guidelines for Assessing Human Health Risks from Environmental Hazards (Ref. 57)
- Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual (Part A) (Ref. 58)
- Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment) (Ref. 59)
- The Air Toxics Hot Spots Program Guidance Manual for Preparation of Health Risk Assessments (Ref. 60).

In general, the HRA process was divided into these tasks:

- Issue Identification
- Hazard Assessment, or ‘Toxicity Assessment’
- Exposure Assessment
- Risk Characterisation.

The HRA was concluded at the end of the risk characterisation stage, which, as described in the DEC’s Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (Ref. 31), consists of comparing the predicted ground-level concentrations of air toxics to the relevant impact assessment criteria.

In summary, where predicted ground-level concentrations of BTEX and H_2S were found to be less than the respective assessment criteria, it was considered that potential health risks were below the level of concern and no further evaluation was warranted.

6.2.6.1 Issue Identification

As the first step in the risk assessment, a Conceptual Site Model (CSM) was developed to identify the source of the Chemical of Potential Concern (COPC), their release and transport mechanisms, exposure pathways, and potential receptor populations that may be exposed to COPCs in an environmental media.

The CSM was relatively straightforward. The source of COPCs was identified as the acid gas separated from the feed gas at the AGRUs. The mechanism of the release consists of planned or unplanned venting of the acid gas to the atmosphere, which then becomes the transport medium. The acid gas released into the atmosphere disperses in the air, and, depending on prevailing wind and meteorological conditions, the dispersed airborne COPCs reach some of the sensitive receptor locations where personnel are working or residing. Finally, the dispersed airborne COPCs come into contact with personnel; exposure would occur via inhalation.

6.2.6.2 Hazard Assessment

The COPCs are those chemicals in the acid gas stream that are present at concentrations high enough to warrant quantitative assessment of potential health risks to human health, or that might pose a nuisance (e.g. odours).

When reviewing the acid gas stream composition, the constituents considered to meet this definition were BTEX and H_2S. The other constituents present in the acid gas (e.g. other VOC constituents) were considered qualitatively; however, they were ruled out for further quantitative assessment based on their lower modelled concentrations and lower toxicity.

For example, methane, ethane, propane, butane, and pentane are all light hydrocarbons that are either gases at standard temperature and pressure, or that would persist as volatiles under a venting-to-atmosphere scenario. These low molecular weight hydrocarbons all have relatively low toxicity; all can produce dizziness, drowsiness, headache, and other signs of central nervous system depression following prolonged exposure at relatively high concentrations. However, under the release scenarios for acid gas being evaluated, the very low ambient concentrations of these VOC constituents were not considered to be of any toxicological concern to humans on Barrow Island. Therefore, these constituents were not included as COPCs.

Furthermore, in the case of n-hexane, which is a neurotoxin in humans and animals, this constituent is present in the acid gas stream at concentrations significantly lower than BTEX (e.g. less than 1% of the concentration of benzene). The physical and chemical properties of n-hexane are similar to those of benzene; therefore, it would be expected to disperse in the atmosphere similar to benzene, although at much lower concentrations. However, the reference toxicity criteria for n-hexane for community and occupational exposures are significantly higher than those for benzene. Therefore, provided that benzene is present below its applicable reference criteria, n-hexane would also be considered to be present at concentrations several orders-of-magnitude below its applicable reference criteria. To confirm this assumption, three separate model runs (using Canary) for n-hexane under worst-case dispersion conditions were completed. In each case, maximum ground-level concentrations of n-hexane reached the 1 ppb lower limit of the Canary model within 600 m of the AGRUs. Furthermore, under the worst-case modelling conditions, the maximum ground-level concentration of n-hexane near the AGRU vents was predicted to be 8 ppb, which is more than 6000-fold lower than the National Occupational Health Exposure Standards standard of

50 000 ppb. Therefore, this constituent was not included as a COPC, and not deemed a credible hazard.

6.2.6.3 Exposure Assessment

As noted above, the CSM identified that exposures could occur at both work and residential locations. Therefore, exposure assessment considered both occupational and residential exposures.

6.2.6.4 Risk Characterisation

Risk characterisation concluded at the risk screening stage, whereby the modelled ambient air quality results were compared to the relevant occupational health exposure and air quality criteria, as listed in Table 2-3 and Table 2-4.

As noted in Section 5.4.2.3, the 2010 ETC modelling study indicated that predicted concentrations of H_2S and BTEX at the selected sensitive receptor locations were all below the relevant residential assessment criteria. For those receptors that were assessed against an occupational health-based assessment criteria, the maximum predicted ground-level concentrations were less than two orders-of-magnitude than the applicable assessment criteria.

Based on these modelling results and the hazard assessment and exposure assessment completed as part of the HRA process, the potential for health risks associated with exposure to BTEX and H_2S during acid gas venting events was determined to be within acceptable levels.

6.2.7 2011 Ecological Risk Assessment

A terrestrial ERA (Ref. 49) and marine ERA (Ref. 50) were undertaken as part of the development of this Plan to assess potential environmental impacts to terrestrial and marine flora and fauna associated with exposure to atmospheric pollutant and air toxics emissions from the GTP. The ERAs were based on effects (where known) of respective atmospheric pollutants and air toxics on the likely exposure pathways to identified sensitive ecological receptor species.

The following steps were undertaken as part of the two ERA studies:

- Characterisation of the Environmental Setting – inclusive of the physical and climatic conditions and sensitive ecological receptors
- Hazard Assessment – a desktop review and literature search on the known effects of atmospheric pollutants and air toxics on terrestrial and marine flora and fauna, including identification of likely exposure pathways
- Effects Assessment – determination of reference dose concentrations for atmospheric pollutants and air toxics, derived from ecotoxicity studies; determination of corresponding levels of environmental impact (harm); and comparison to predicted concentrations of atmospheric pollutants and air toxics to assess the potential for adverse health impacts on terrestrial and marine flora and fauna
- Exposure Assessment – identification of the exposure potential of individual flora and fauna species, including listed and general fauna, restricted and general flora, and vegetation associations
- Risk Characterisation – assessment of the risks to terrestrial and marine flora and fauna, associated with the presence of atmospheric pollutants and air toxics, using CAPL's HES Risk Management Process (Ref. 61).

Each of the above steps and the conclusions of the risk assessment are discussed in the following sections.

6.2.7.1 Environmental Setting

The climatic conditions, topography, geology, and hydrogeology of Barrow Island and its surrounding marine environment were considered relevant to understanding the impacts of atmospheric pollutants and air toxics on terrestrial and marine flora and fauna, as these facilitate a number of processes involved in the distribution, deposition, uptake, and final fate of these chemicals.

The ecological components of Barrow Island and its surrounding marine environment were also characterised, including terrestrial and marine flora and fauna, and identification of those species whose distribution was restricted to Barrow Island, or those with a formal listing under State or Commonwealth Acts.

6.2.7.2 Hazard Assessment

The hazard assessment step included these tasks:

- Identify a comprehensive list of atmospheric pollutants and air toxics, derived from the SKM (Ref. 36; Ref. 38, Ref. 39) and ETC (Ref. 47) air quality modelling studies, and the list of chemicals reported by other LNG Plant Operators (e.g. Woodside) on the NPI website. Emission rates and ambient ground-level concentrations for chemicals not included in the scope of this Plan were derived from reported NPI values for Woodside's Pluto Gas Treatment Plant on the Burrup Peninsula (Ref. 62) and extrapolated from SKM's TAPM modelling results (the most conservative chemical dilution rate in the atmosphere). Predicted ambient concentrations were compared against known effect concentrations as published in the scientific literature. This pre-screening exercise indicated that the pollutants peak and annual average ambient concentrations were at least an order-of-magnitude lower than their designated reference concentrations. This exercise also showed that there are unlikely to be any other chemicals of concern (known to be emitted from a typical gas treatment plant) other than those already identified in the scope of this Plan that could reasonably be expected to cause adverse health impacts to terrestrial and marine flora and fauna.
- Review and summarise the literature related to known adverse effects of the key atmospheric pollutants (NO_2, PM_{10}, SO_2, O_3, PAHs) and air toxics (H_2S and BTEX) emitted from the GTP and the likely fate of these chemicals in the ambient environment (e.g. dispersion, conversion in the atmosphere to other chemicals, deposition).
- Identify the likely credible exposure pathways for atmospheric pollutants and air toxics to assess potential impacts to terrestrial and marine flora and fauna (e.g. respiration, skin absorption or ingestion, bioaccumulation/ biomagnification, increase in nutrient loading levels). This information was used in determining the potential exposure risk in the exposure assessment step, discussed in Section 6.2.7.4.

6.2.7.3 Effects Assessment

The purpose of the Effects Assessment step was to determine the extent of the air quality impact footprint (both spatially and in time) from routine and non-routine operations of the GTP. To do this, it was necessary to:

- determine reference concentrations (RfCs) for each atmospheric pollutant and air toxic that might reasonably lead to adverse health impacts on terrestrial and marine flora and fauna, taking into consideration various uncertainty factors (UFs)
- compare predicted ambient ground-level concentrations of the atmospheric pollutants and air toxics at specified distances from the GTP fence line against those RfCs, and link to the potential for Environmental Harm
- determine the frequency of the conditions related to potential Environmental Harm derived from GTP operational and meteorological data.

The effects assessment approach differed for routine and non-routine GTP operating conditions.

Since the common atmospheric pollutants during routine operations were modelled using the TAPM software, a good local and regional distribution of the peak and annual average ground-level concentrations of these pollutants was provided by the model. Based on the predicted peak ground-level concentrations of these pollutants, their probabilistic distribution over a year, their deposition rates, and the known effects of these chemicals, it was concluded that the routine emissions from the GTP are unlikely to lead to anything more than short-term reversible impacts on the terrestrial and marine flora and fauna (i.e. equivalent to a worst-case consequence of Environmental Harm).

For non-routine operations, acid gas venting and the associated H_2S and BTEX emissions were examined more closely in consideration of the eco-toxicological properties of these chemicals. Reference concentrations of these chemicals in air were derived from published scientific data, as summarised in the USEPA Risk Assessment Guidance for Superfund (Ref. 59). Reference concentrations were derived by applying UFs to published toxicological data that determines either the Lowest Observable Adverse Effects Level (LOAEL) or No Observable Adverse Effects Level (NOAEL). The LOAEL is the lowest published concentration at which adverse health effects could still be observed. The NOAEL is the highest published concentration at which adverse health effects could not be observed. The difference between these two levels is an area of uncertainty. The following UFs were applied to these values to derive a RfC:

- variation in susceptibility among the members of the exposed population (e.g. laboratory animals are initially fit and healthy, whereas in a natural setting animals survive in less than ideal conditions). A factor of 10 was applied for this UF
- uncertainty in extrapolating from mammals to marsupials, or from mammals to air-breathing marine fauna. As there appears to be considerable differences between the biochemistry of terrestrial placental mammals and that of marsupials and marine placental mammals, a factor of 10 was applied for this UF
- uncertainty in extrapolating from a LOAEL rather than a NOAEL. A factor of 10 was applied for this UF, in line with USEPA recommendations
- uncertainty in data obtained in a study with less-than-lifetime exposure. The USEPA typically apply a factor of 10 to extrapolate from short-term studies to lifetime exposures. Since non-routine operations are typically short term, it was considered unwarranted to apply an additional UF in this case.

With the above rules in place, the RfCs listed in Table 6-2 were derived from laboratory studies for the air toxics associated with H_2S and BTEX. These RfCs have been mapped to environmental harm and environmental consequence levels respectively, as per the Chevron RiskMan2 Methodology (Ref. 63).

Table 6-2: Derived Reference Concentrations for H_2S, Benzene, Toluene, and Xylene

Reference Concentration	Impact of Continuous Exposure	Level of Environmental Harm	RiskMan2 Consequence Level	Derived RfC Concentration [ppm]			
				H_2S	Benzene	Toluene	Xylene
NOAEL RfC	None below this level	--	--	0.07 (0.014)[1]	0.09	1.2	0.07
LOAEL RfC	Short-term reversible impacts above this level on susceptible individuals	Environmental Harm	Incidental	0.25 (0.044) [1]	0.44	3.9	0.14
LOAEL RfC × 2	Long-term non-reversible impacts above this level on susceptible individuals	Material Environmental Harm	Minor	0.5 (0.088) [1]	0.88	7.8	0.28
LOAEL RfC × 10	All individuals experience at least short-term reversible impacts	Serious Environmental Harm	Moderate	2.5 (0.44) [1]	4.4	39	1.4
LOAEL RfC × 20	All individuals experience long-term non-reversible impacts	Serious Environmental Harm	Major	5 (0.88) [1]	8.8	78	2.8

Notes:

1. *The different RfC concentrations for H_2S shown in brackets are associated with UFs applied for air-breathing marine fauna (e.g. cetaceans and dugongs) as opposed to those applied to small terrestrial marsupials. The USEPA initially translated the impact from small mammals (e.g. rats) to humans by allowing an additional factor of 5.4 to be applied for differences in the ventilation rates. This correction was applied when considering cetaceans and dugongs, but was not deemed necessary when considering small terrestrial marsupials.*

A comparison of the RfCs listed in Table 6-2 to the predicted ground-level concentrations of these air toxics outside the GTP fence line concluded:

- Predicted ground-level concentrations of H_2S and BTEX under all modelled acid gas venting scenarios for the GTP indicate no potential for Material or Serious Environmental Harm on terrestrial and marine flora and fauna.
- If simultaneous venting of acid gas from all three AGRU trains occurred, ground-level concentrations for benzene within 50 m of the GTP northern fence line were predicted to be greater than the LOAEL RfC (which is equivalent to Environmental Harm), but not greater than two times the LOAEL RfC, i.e. there is potential for short-term reversible impacts to susceptible individuals within this 50 m zone. However, simultaneous venting of acid gas from all three AGRU trains is expected to occur once in five years over a maximum period of five days (due to pigging of the CO_2 Injection Pipeline). For

these impacts to potentially occur, two other conditions would need to occur at the same time—the wind would need to be from the south-west quadrant to carry the acid gas plume outside the northern fence line, and the weather stability class would need to be Category E or F. On an annual basis, the calculated cumulative probability of all these events occurring is 0.07%, representing 6 hours in a year. In addition, the 50 m impact zone for this event lies within the Terrestrial Disturbance Footprint for the construction phase, which currently extends to 100 m for non-mobile ecological elements (flora) and 1000 m for fauna outside the GTP fence line (Ref. 64).

As all fauna moves freely on Barrow Island, and as the Island is visited frequently by migratory birds and marine turtles, the exposure assessment examined the likelihood, or potential, for this fauna to be affected by the predicted ambient ground-level concentrations of atmospheric pollutants and air toxics. The exposure assessment also considered the flora on Barrow Island, as well as the surrounding marine environment.

6.2.7.4 Exposure Assessment

The purpose of this assessment was to identify which species are inherently more at risk from the atmospheric pollutant and air toxics emissions from the GTP, either because they are more susceptible to such impacts due to their lifestyle, or due to their rare, endangered, or protected status.

6.2.7.4.1 Exposure Assessment for Terrestrial Fauna

The ecological criteria considered in the assessment for terrestrial fauna included occurrence, mobility, typical habitats, and population size, among others. A score was assigned to each ecological criteria depending on additional ecological factors, as shown in Table 6-3.

Table 6-3: Ecological Criteria and Factors Influencing Exposure Risk in Terrestrial Fauna

Criteria	Ecological Factor	Score	Max Score
Occurrence Behaviour	Visitor-vagrant	1	3
	Seasonal	2	
	Resident	3	
Exposure Duration (Behaviour)	Diurnal or nocturnal	1	2
	24-hour exposure	2	
Refuge or Shelter	Burrow or shelter	1	3
	Rock crack or crevice	2	
	Exposed	3	
Mobility	Unrestricted	1	4
	High (>10 ha <100 ha)	2	
	Moderate (>1 ha <10 ha)	3	
	Low (<1 ha)	4	
Habitat Specificity	Uses more than one habitat	1	2
	Habitat restricted	2	
Threatened Species	Not listed	1	4
	Commonwealth or State listing	4	

Criteria	Ecological Factor	Score	Max Score
Abundance (Population Size)	>5000	1	3
	1001 – 5000	2	
	001 – 1000	3	
Maximum Potential Score: 21			

The final outcomes for terrestrial fauna were presented in three bands of exposure potential:

- High Exposure Potential is the exposure potential calculated to be between 70% and 100% of the maximum potential score of 21. Typically, this potential reflects species of high conservation value that are resident on Barrow Island, or that inhabit only restricted habitats near the GTP.
- Medium Exposure Potential is the exposure potential calculated to be between 50% and 70% of the maximum potential score of 21. Species within this group will be more common species, visiting species, or species with wide habitats that are typically distant from the GTP.
- Low Exposure Potential is the exposure potential calculated to be between 0% and 50% of the maximum potential score of 21. Species within this group are common and unlisted species that are abundant on Barrow Island and the mainland, or species that visit the Island only for a small fraction of the year, and that are distant from the GTP.

The assessment of the exposure potential for terrestrial fauna resulted in these conclusions (only high exposure results listed):

- Five species of terrestrial mammals were found to have high exposure potential—Black-flanked Rock Wallaby, Barrow Island Euro, Western Chestnut Mouse, Burrowing Bettong, and Common Rock Rat.
- Six species of avifauna were found to have high exposure potential—Osprey, White-bellied Sea-eagle, White-winged Fairy-wren (Barrow Island), Grey-tailed Tattler, Ruddy Turnstone, and Red-necked Stint.
- One species of herpetofauna (subterranean Blind Snake) was found to have high exposure potential.
- Stygofauna exposure potential was estimated as low due to the limited number of exposure pathways.
- There are at least 1460 invertebrate species on Barrow Island, with none restricted to the Terrestrial Disturbance Footprint. As data are absent on the scarcity and significance of these species, it was impossible to determine the significance of exposure of any particular species.

6.2.7.4.2 Exposure Assessment for Terrestrial Flora

The exposure risk assessment for terrestrial flora examined the vegetation communities near the GTP.

No plant communities listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) have been recorded or are known to occur on Barrow Island. No Threatened Ecological Community species (as listed on the WA Department of Biodiversity, Conservation and Attractions

Threatened and Priority Fauna, Flora or Ecological Communities database) has been recorded or is known to occur on Barrow Island.

Three restricted flora species have been recorded in vegetation associations in the combined clearing area for the Gorgon Gas Development. These species are not protected by legislation; however, they are considered to be of conservation interest because they are either restricted in distribution on Barrow Island or have low regeneration rates after disturbance.

With respect to overall exposure risk, it would be reasonable to conclude that there is potential for short-term reversible impacts to susceptible vegetation species within 50 m of the northern GTP fence; however, it is considered unlikely to result in any visible impacts.

6.2.7.4.3 Exposure Assessment for Marine Flora and Fauna

For the exposure assessment for marine flora and fauna, the primary consideration related to potential exposure pathways, and the likelihood of exposure occurring. The findings of the exposure assessment for each pathway are summarised below.

Dermal Contact

Predicted concentrations of atmospheric pollutants and air toxics emissions from routine operations are sufficiently low that they are unlikely to cause health impacts to marine flora or fauna via dermal contact.

As noted in Section 6.2.7.3, during non-routine operations (specifically, if simultaneous venting of acid gas from all three AGRU trains occurs), ground-level concentrations for benzene within 50 m of the GTP's northern fence line are predicted to be greater than the LOAEL RfC (which is equivalent to Environmental Harm), but not greater than two times the LOAEL RfC (i.e. there is potential for short-term reversible impacts to susceptible individuals within this 50 m zone). However, this is not expected to affect the marine environment, which is more than 1000 m from the AGRU trains.

Elevated ground-level concentrations of H_2S and BTEX above background levels may occur within the marine environment; however, the concentrations are considered insufficient to cause adverse health impacts to marine flora or fauna via dermal contact.

Respiration

As noted above, predicted concentrations of atmospheric pollutants and air toxics emissions from routine operations are sufficiently low that they are unlikely to cause health impacts to marine flora or fauna via respiration.

For non-routine operations, elevated ground-level concentrations of H_2S and BTEX above background levels may occur within the marine environment; however, the concentrations are considered insufficient to cause health impacts to marine flora or fauna via respiration.

Ingestion (and Bioaccumulation)

The dilution factors related to emission loading (via deposition) and seawater volumes indicate that for most atmospheric pollutants and air toxics there are unlikely to be viable exposure pathways for marine flora and fauna. Although elevated concentrations of these pollutants above background levels may occur

within the marine environment, these are sufficiently low that they are unlikely to cause health impacts to marine flora or fauna via ingestion.

Section 1.6 (specifically, Table 1-4) noted that the GTP has the potential to emit pollutants that are known to bioaccumulate (e.g. Hg, PAHs, polychlorinated biphenyls [PCBs], and dioxins). However, these pollutants were excluded from the scope of this Plan as they are considered low risk due to their low emission rates during the commissioning and start-up, and operation of the GTP.

A very conservative screening assessment indicated that Hg concentrations could be within two orders-of-magnitude below the relevant Australian and New Zealand Environment and Conservation Council (ANZECC) Guidelines criteria (Ref. 65). However, ANZECC specifically excludes consideration of bioaccumulation in the setting of these criteria.

Furthermore, no criteria are set within the ANZECC Guidelines for suitable concentrations of PAHs, PCBs, or dioxins, as no literature indicates an appropriate dose–response relationship.

Therefore, in the absence of suitable guidance, it was not possible to quantify exposure via bioaccumulation.

Nutrient Impacts

The assessment of potential nutrient impacts adopted a very conservative approach of assuming that all NOx were dissolved by reaction with sea water to form nitrate within a 90 km zone around the GTP. The results of this calculation suggested that, if this were to happen, the concentrations would exceed the ANZECC criteria for nitrate (as N) for tropical onshore waters. However, the rates of reaction associated with this assumption are unrealistic. It is highly unlikely that all the NO react to form NO_2 as sufficient available O_3 is absent within the modelling domain.

6.2.7.5 Risk Characterisation

Risk Characterisation is the final step in the ERA studies, which brings together these components:

- the extent of the areas around the GTP where Environmental Harm could occur under certain operating conditions and the potential consequences to terrestrial and marine flora and fauna
- the frequency and duration of experiencing ground-level concentrations in those areas that are linked to the respective levels of Environmental Harm.

Although the exposure potential assessment identified the species that could be most adversely affected if RfCs related to Environmental Harm were exceeded, this assessment has no direct bearing on the final risk results.

CAPL's HES Risk Management Process (Ref. 61) was applied to characterise the risks associated with the results. The findings and conclusions of the two ERA studies (terrestrial and marine) are summarised below.

6.2.7.5.1 Risk Characterisation for Terrestrial Flora and Fauna

Using the results of the assessments, and the consequence categories outlined in the RiskMan2 Procedure (Ref. 63), impacts from emissions associated with routine and non-routine operations on terrestrial flora and fauna are restricted to Environmental Harm within 50 m of the GTP's northern fence line during the

worst-case emission scenario of simultaneous venting of acid gas from all three AGRU trains.

Since it is considered likely that this level of Environmental Harm would be experienced in the life of the GTP, the corresponding risk level is equivalent to Category 6 (or 'as low as reasonably practicable' risk).

6.2.7.5.2 Risk Characterisation for Marine Flora and Fauna

Using the results of the above assessments, and the consequence categories outlined in the RiskMan2 Procedure (Ref. 63), impacts from emissions associated with routine and non-routine operations on marine flora and fauna via dermal contact, respiration, ingestion, and nutrients are unlikely to cause any adverse health impacts.

Bioaccumulation impacts were found to be unquantifiable, owing to the absence of suitable guidance.

6.2.7.6 Conclusions

For routine operations, it is reasonable to conclude that the predicted concentrations of atmospheric pollutants and air toxics are not expected to result to anything more than short-term, reversible impacts on terrestrial and marine flora and fauna. It is highly unlikely that any impacts will be observed from the predicted concentrations.

For non-routine operations, given the degree of conservatism adopted and considering the transient nature of the non-routine emissions (specifically for acid gas venting), it is reasonable to conclude that no more than Environmental Harm (i.e. short-term, reversible impacts) will occur to terrestrial and marine flora and fauna.

Based on the results of the ERAs, the potential for environmental risk to terrestrial and marine flora and fauna associated with exposure to atmospheric pollutants and air toxics is considered to be acceptable.

6.2.8 2014 Screening-level Health Risk Assessment

The starting point for the HRA was reviewing the modelling results that predicted Hg concentrations in the atmosphere at key sensitive receptor locations on Barrow Island where workers may be exposed. The next step was to compare the ground-level concentrations against appropriate ambient air quality standards and standards for human health in the workplace for personnel working on Barrow Island; these standards were considered conservative and represented screening levels below which no adverse health impacts would be expected. This process and the conclusions of the HRA are summarised in the following sections.

6.2.8.1 Conceptual Site Model

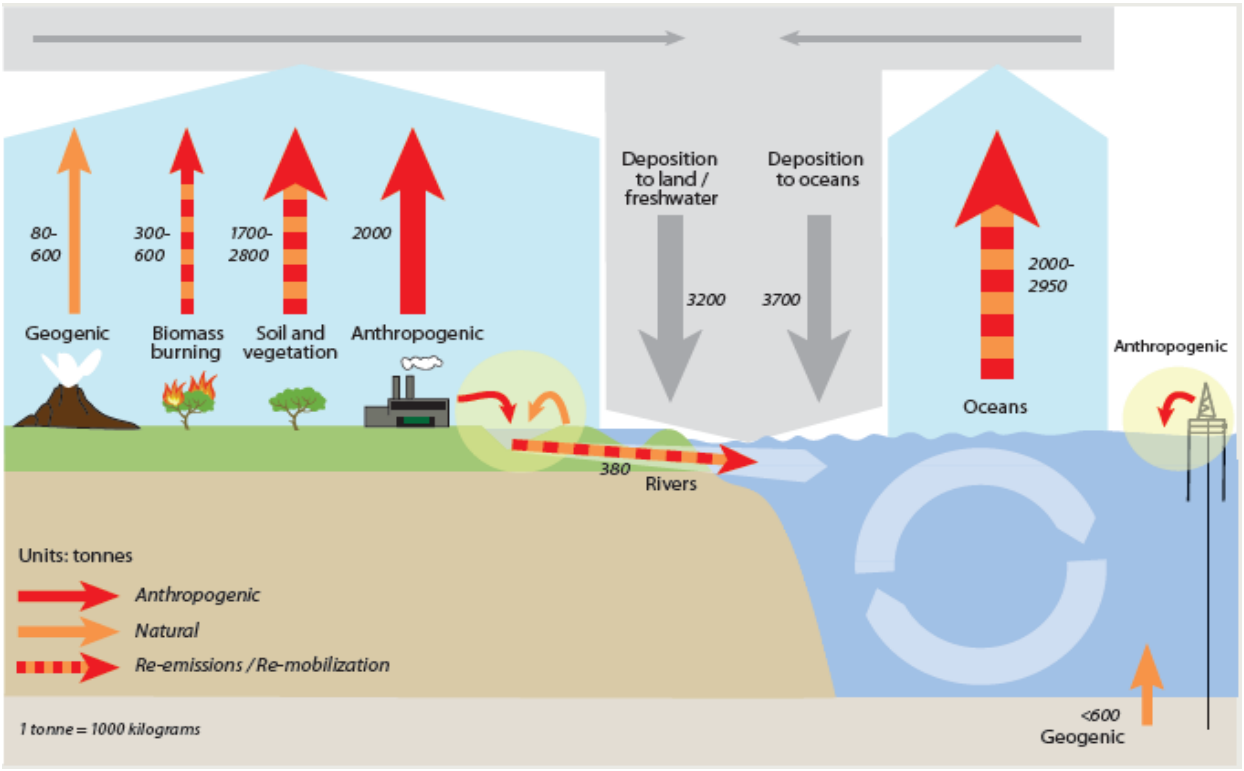
The first step was to develop a CSM, aimed at identifying the sources of Hg, the release and transport (fate) mechanisms, exposure pathways, and potential receptor populations that may be exposed to Hg.

The sources, release mechanisms, and potential receptor populations were aligned with the 2014 Air Assessments modelling study (Ref. 41). The transport (fate) mechanisms and exposure pathways were based on available anecdotal evidence from literature reviews, which are summarised below.

Mercury is a unique metal as it exists in a gaseous phase. Because of its relatively low deposition velocity and high vapour pressure, more than 95% of Hg in the atmosphere exists as gaseous elemental Hg. The residence time of Hg in the atmosphere is about one year. Mercury emissions can be transported throughout a hemisphere or globally. Because of its global reach, the evaluation of Hg transport and fate must consider the global cycling of gaseous elemental Hg in addition to transport by surface water and groundwater. Atmospheric deposition in precipitation (known as wet deposition) and dust (known as dry deposition) are the primary sources of Hg in the environment.

Numerous authors have developed global estimates of natural and anthropogenic emission sources and deposition sinks, which reflect the uncertainty and evolving understanding of the global mass balance of Hg. The most recent compilation is the Global Mercury Assessment 2013 by the United Nations Environment Programme (Ref. 66). Figure 6-1 illustrates the main environmental compartments (air, land, and water) and the pathways of the global Hg cycle. Note: More than 50% of Hg deposited on land is re-emitted as gaseous elemental Hg to the atmosphere.

The exposure pathways considered relevant for personnel working on Barrow Island were inhalation and/or direct contact via ingestion or dermal contact, with these exposures occurring at both work and residential locations.



Source: Ref. 66

Figure 6-1: Principal Environmental Compartments (Air, Land, and Water) and Pathways of the Global Mercury Cycle

6.2.8.2 Hazard and Exposure Assessment

In summary, Hg emissions are expected to be very low. Overall, no change to the equilibrium between gaseous elemental Hg in the atmosphere and deposited Hg in soil and water is expected, with no significant net deposition of gaseous elemental Hg likely to occur.

6.2.8.3 Risk Characterisation

As noted in Section 5.5, the 2014 Air Assessments modelling study (Ref. 41) indicated that predicted concentrations of Hg at the selected sensitive receptor locations were all below the relevant residential assessment criteria. For those receptors assessed against occupational health assessment criteria, the maximum predicted ground-level concentrations were also less than the applicable assessment criteria.

Based on these modelling results and the hazard assessment and exposure assessment completed as part of the HRA process, the potential for health risks associated with exposure to Hg was determined to be within acceptable levels.

6.2.9 2014 Ecological Risk Assessment

The screening-level ERA involved developing a CSM to identify potentially complete exposure pathways to sensitive receptors and/or habitats, and comparing estimated Hg deposition rates to, and concentrations in, soil and water against background levels to determine if increases above background, if any, have the potential to cause unacceptable risk to ecological receptors. This process and the conclusions of the ERA are summarised in the following sections.

6.2.9.1 Conceptual Site Model

The climatic conditions, topography, geology, and hydrogeology of Barrow Island and its surrounding marine environment were considered relevant to understanding the impacts of Hg on terrestrial, subterranean, littoral, and offshore marine habitats on and around Barrow Island, as these facilitate a number of processes involved in the distribution, deposition, uptake, and final fate of this chemical.

The ecological components of Barrow Island and its surrounding marine environment were also characterised, including terrestrial and marine flora and fauna, along with identification of those species whose distribution was restricted to Barrow Island, or those with a formal listing under State or Commonwealth Acts.

Figure 6-2 illustrates the CSM for the potential exposure pathways and receptors for these habitats.

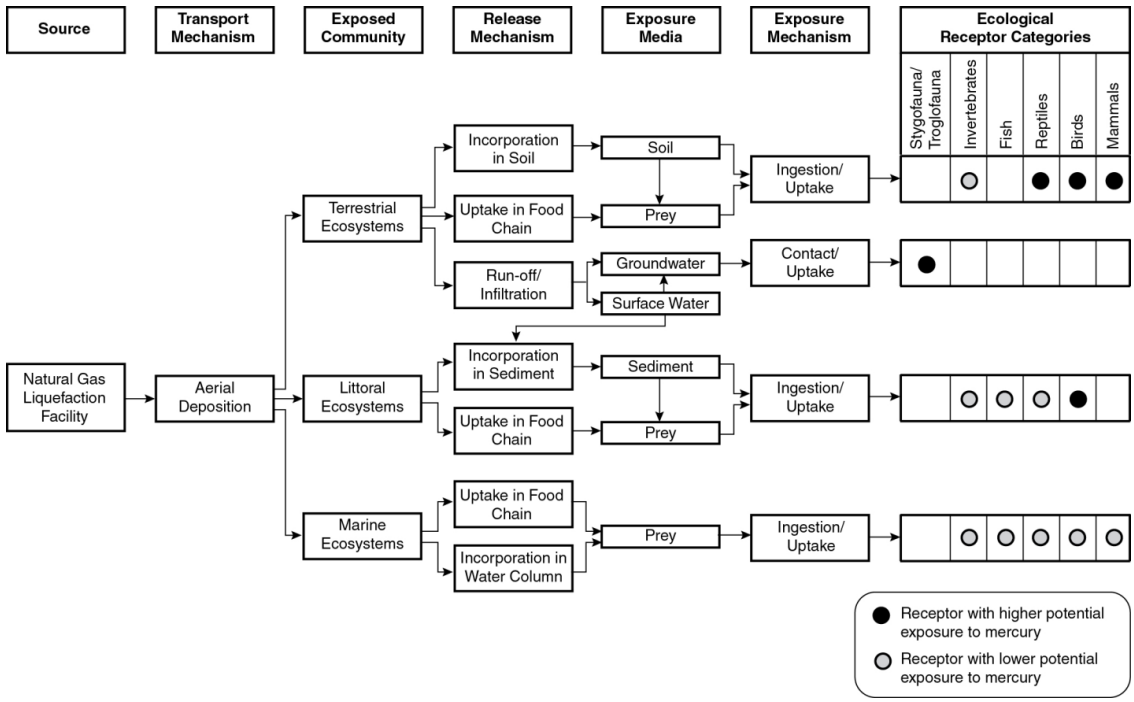


Figure 6-2: CSM of Potential Exposure Pathways and Receptors for Identified Habitat Types on and around Barrow Island

6.2.9.2 Hazard and Effects Assessment

The hazard and effects assessment included these key tasks:

- review the scientific literature for known adverse effects from Hg and the likely fate of this chemical in the environment (e.g. dispersion, deposition)
- compare the predicted deposition rates against known effect concentrations for Hg as published in the scientific literature. This screening exercise indicated that the predicted deposition rates were well below the designated reference concentrations
- identify the likely credible exposure pathways to assess potential impacts to terrestrial and marine flora and fauna (e.g. respiration, skin absorption or ingestion, bioaccumulation/biomagnification). This information was used to determine the potential exposure risk in the exposure assessment step.

6.2.9.3 Exposure Assessment

The exposure assessment step identified the species that are inherently more at risk from Hg emissions, either because their life history makes them more susceptible to such impacts, or because of their rare, endangered, or protected status.

6.2.9.4 Risk Characterisation

Risks were evaluated qualitatively for selected ecological receptors from four habitat types on and around Barrow Island where Hg deposition may occur. For all habitats, the likelihood of an incremental risk to receptors was considered negligible for all operating scenarios.

In terrestrial habitats, assuming 40 years of deposition with no losses from the soil, the estimated soil Hg concentration is expected to remain greater than one order-of-magnitude below the relevant ecological investigation level. Therefore, the likelihood of increased Hg deposition raising current soil Hg concentrations above the screening threshold is very low.

As it is retained on surface soils, Hg is not expected to infiltrate into the groundwater. Prior studies have shown little measurable groundwater fluctuation caused by precipitation events, suggesting that run-off from surface soils to subterranean habitats is not a significant pathway on Barrow Island. Additionally, the incremental contribution of Hg deposition to terrestrial habitats is expected to be negligible. Therefore, because of the apparent absence of a major transport pathway and the limited amount of Hg that would be transported to groundwater in any precipitation event, the risk to subterranean fauna is considered negligible.

Receptors of greatest concern in littoral habitats are migratory shorebirds; several species use Barrow Island in high numbers as a stopover point during migration. Based on previous surveys of bird use of Barrow Island, most migrants appear to congregate in areas downstream of catchment basins where Hg deposition is lowest, which would minimise overall levels of exposure. Similarly, mangrove habitats and most marine turtle nesting beaches are also downstream of catchment basins with low Hg deposition. The incremental addition of Hg to littoral habitats is negligible because of the low deposition rates. Therefore, the risk to littoral receptors is considered negligible.

Mercury deposition in marine waters is also negligible, and deposition rates decrease rapidly moving away from Barrow Island. Therefore, the likelihood that surface water Hg concentrations would show a substantial increase over background levels is low, and the footprint where that increase may occur would be spatially limited. In addition, Hg that may be deposited would be diluted quickly through the dispersive actions of tides and currents. Therefore, the risk to receptors in marine habitats is considered negligible.

Based on the results of the ERA, the potential for environmental risk to terrestrial and marine flora and fauna associated with exposure to Hg is considered acceptable. It is highly unlikely that any impacts will be observed from the predicted concentrations.

6.3 Commissioning and Start-up Period

6.3.1 Anticipated Atmospheric Emissions

Based on experience from other projects, the current understanding of the commissioning and start-up sequence, and the schedule for the GTP, this period of the Gorgon Gas Development is expected to be characterised by:

- relatively short-duration purging of nitrogen via the ground flares followed immediately by hydrocarbon venting prior to commissioning (lighting) of the ground flares. It is envisaged that such venting could last from several hours to several days. Flares are to remain operating on pilot and purge fuel gas only
- prolonged flaring at higher than routine flaring rates as sections of the GTP are progressively commissioned. Additional flaring is expected to result from major activities such as:
  - import of DomGas to support commissioning of the Frame 9 GTGs

  - import of LNG to support commissioning of the LNG storage (tanks) and loading system
  - start-up of the subsea systems and purging of the feed gas pipelines
  - start-up of the CO_2 Injection System
  - defrosting of the LNG trains
  - managing the ramp-up of feed gas production associated with pipeline liquid inventory management
  - start-up of the DomGas system
  - frequent trips of major GTP machinery such as the Frame 9 GTGs and Frame 7 GTs and the need to safely evacuate gas inventories when restarting affected parts of the GTP
- prolonged acid gas venting until all components of the CO_2 Injection System, including wells, are commissioned.

Note: Although the CO_2 Injection System is designed to dispose by underground injection 100% of the volume of reservoir CO_2 to be removed during routine processing operations, it is not feasible to inject CO_2 during initial start-up and Jansz-only operations.

Many of the above scenarios, excluding hydrocarbon venting prior to commissioning the ground flares, are likely to occur simultaneously and at various stages during the commissioning and start-up of the three LNG trains. As a result of this staged commissioning and start-up approach, emissions occurring as a result of the worst-case flaring and acid gas venting rates modelled for the 'Emergency Shutdown' and 'Acid Gas Venting' operating scenarios (discussed in Sections 5.2.2.5 and 5.2.2.6 respectively) are not expected to occur.

The planned commissioning and start-up sequence is expected to significantly influence the duration of hydrocarbon gas venting/flaring and acid gas venting activities. This will also allow the implementation of reasonable measures to minimise atmospheric pollutant emissions associated with commissioning and start-up activities.

Section 7 outlines the air quality management measures identified to date that are to be implemented on the Gorgon Gas Development.

6.3.2 Compliance with National Ambient Air Quality Standards

The conclusions drawn from the discussions in Section 6.2 suggest that ground-level concentrations of atmospheric pollutants and air toxic emissions are estimated to remain below the relevant NEPM assessment criteria; therefore, ambient air quality is expected to be acceptable.

This is based on the assumption that emissions of atmospheric pollutants and air toxics during the commissioning and start-up period are expected to closely resemble the modelled non-routine operating scenarios of 'Emergency Shutdown' and 'Acid Gas Venting' (see Sections 5.2.2.5 and 5.2.2.6).

6.3.3 Compliance with National Occupational Health Exposure Standards

Of the routine and non-routine operations considered during the various modelling studies, prolonged acid gas venting presents the greatest potential for exposure of personnel to low-level air toxics in the ambient environment.

However, the staged commissioning and start-up of the three LNG trains, and the progressive commissioning of each process system inside each train, is expected to ensure that the worst-case acid gas venting scenario of three AGRUs simultaneously venting at the peak acid gas production rates remains highly unlikely.

As is evident from the conclusions drawn on occupational health impacts (Section 6.2.2), ground-level concentrations of atmospheric pollutants and air toxic emissions for all scenarios modelled to date (including worst-case acid gas venting) are estimated to remain below the relevant occupational exposure standards; therefore, ambient air quality associated with acid gas venting during the commissioning and start-up period is expected to be acceptable.

6.3.4 Compliance with Non-occupational Health Exposure Criteria

As noted in Section 6.2.4, ground-level concentrations of BTEX and H_2S emissions during acid gas venting are estimated to remain below the relevant impact assessment criteria; therefore, ambient air quality is expected to be acceptable. It is reasonable to expect that as the commissioning and start-up period closely resembles the modelled non-routine operating scenarios of 'Emergency Shutdown' and 'Acid Gas Venting' (Sections 5.2.2.5 and 5.2.2.6), the ambient air quality during such events in the commissioning and start-up period is also expected to be acceptable.

6.3.5 Compliance with Mercury Criteria

As noted in Section 6.2.5, ground-level concentrations of Hg emissions for all scenarios modelled are estimated to remain below the relevant impact assessment criteria; therefore, ambient air quality is expected to be acceptable during routine and non-routine operations.

6.3.6 Other Environmental Criteria

Potential impacts on terrestrial and marine flora and fauna due to atmospheric pollutant emissions and air toxics and their associated impacts during the commissioning and start-up period are expected to have similar consequences to those discussed for the operations phase of the GTP (Section 6.2.7).

While the number of non-routine operating scenarios modelled for the operations phase are expected to be far more frequent during the commissioning and start-up phase, and therefore pollutant concentrations are expected to peak more often, the staged commissioning of the GTP and the short duration of this period is expected to ensure that impacts on air quality, and consequent impacts on terrestrial and marine flora and fauna, are kept within acceptable levels.

6.4 Temporary Flaring of MEG Flash Vapour

6.4.1 Background

MEG flash vapour is a waste gas produced during the MEG regeneration process. The Gorgon Liquified Natural Gas Project Licence (L9102/2017/1) authorises venting to atmosphere of these vapours, and this occurred during commissioning/start-up. The long-term solution for this waste gas is to re-route it to the condensate stabilisation compressor for processing through the inlet facilities, which will allow MEG flash gas vapours to be treated and/or separated via existing facilities such that there are no routine air emissions during normal operations. To reduce air emissions during design and construction of the long-

term infrastructure, approval to construct and temporarily operate facilities that allow MEG flash gas vapours to be routed to the wet gas flare was sought via a Works Approval application submitted to DWER on 6 December 2018. Operation of the facilities that allow MEG flash gas vapours to be routed to the wet gas flare and combusted was approved under Works Approval (W6199/2018/1).

A subsequent Works Approval application was submitted to DWER in January 2020, to seek approval to:

- construct and operate long-term infrastructure for re-routing MEG flash gas vapours to the Condensate Stabilisation Overhead Compressor on Train 1 and Train 2 where gas will be directed back to the LNG Plant inlet facilities.
- temporarily continue the current combustion of MEG flash gas vapours at the wet gas flare, via operation of the existing facilities approved under W6199/2018/1, until such time as the long-term facilities described above are operational.

This application included the submission of an updated AQMP (this Plan) and the BPPCDR (Ref. 12).

6.4.2 Air Quality Assessments

Modelling studies were undertaken to predict air emissions for this scope:

- In 2018, Worley were commissioned to undertake modelling to determine MEG Flash Vapour Compressor discharge destination (Ref. 44)
- In March 2019, DWER requested that the assessment undertaken by Worley (Ref. 44) be updated based on the outcomes of the EVR Assessment (Ref. 42). Ramboll were commissioned to undertake modelling of BTX and mercury emissions using the TAPM model in conjunction with revisions to relevant geophysical parameters and emissions sources (Ref. 45).
- In December 2019, Ramboll completed a Technical Note addendum (Ref. 46) to the modelling, which reviewed predicted Ground Level Concentrations (GLCs) of BTX and mercury resulting from different flow rates of MEG flash vapour to the wet gas flare. The flow rates included the theoretical design maximum (2.5 kg/s), the maximum and average rates from process monitoring over the period of flaring between 1 August and 16 December 2019, and the predicted maximum and average rates resulting from process upsets during operations.

Ramboll's 2019 assessments (Ref. 46) were provided to DWER as Appendix 8A in the Works Approval application submitted to DWER in January 2020.

Refer to Table 5-1 for further detail.

6.4.3 Modelling Results

Ramboll (Ref. 46) modelled BTX and mercury emissions from the ground flare to produce predicted GLCs across the modelling domain, which were then compared to nominated ambient standards (Ref. 22; Ref. 23; Ref. 31).

The modelling results indicated that predicted mercury and BTX concentrations, from flaring of MEG flash vapours were well below the ambient air quality standards at all modelled sensitive receptor locations. It would be expected that the use of the Wet Gas Flare will result in reduced ambient concentrations as a result of the 98% destruction of BTX and the increased plume buoyancy and dispersion (Ref. 46).

GLCs resulting from the various flow rates modelled (see above) were compared with relevant human health standards, including residential exposure criteria for mercury (Table 2-5). Table 6-4 presents the maximum predicted GLCs (at any of the modelled receptor locations on Barrow Island) for each pollutant and averaging period as a percentage of the relevant health standard from the flaring of MEG flash vapour at the different flow rates. These results range from 0.0000001% to 1.1% of the corresponding standard.

Table 6-4: Maximum Predicted GLCs from Flaring across the 13 Nominated Receptors (presented as percentage of the corresponding standard)

Compound	Averaging period	Criteria (µg/m³)	MEG flash vapour flow rate				
			Design Maximum	Measured Maximum	Measured Average	Upset Maximum	Upset Average
			2.5 kg/s	0.25 kg/s	0.14 kg/s	0.67 kg/s	0.33 kg/s
			GLC % of Criteria				
Hg (total inorganic)	1 hr	1.8	1.1%	0.1%	0.1%	0.3%	0.2%
Hg (elemental)	Annual	0.2	0.1%	0.01%	0.004%	0.02%	0.01%
Benzene	Annual	9.6	0.01%	0.001%	0.001%	0.004%	0.002%
Toluene	24 hr	3769	0.0001%	0.00001%	0.00001%	0.00003%	0.00002%
	Annual	377	0.0001%	0.000009%	0.00001%	0.00002%	0.00001%
Xylene	24 hr	1085	0.00002%	0.000002%	0.000001%	0.000005%	0.000002%
	Annual	868	0.000002%	0.0000002%	0.0000001%	0.0000004%	0.0000002%

Ramboll's modelling predicted that mercury concentrations would be well below the National Occupational Health Exposure Standards (Table 2-6; Ref. 46).

6.5 Conclusions

Based on the above discussions on ambient air quality, occupational and non-occupational human health exposures, and potential impacts to terrestrial and marine flora and fauna, it is concluded that ambient air quality during the commissioning, start-up, and operations phases, including during non-routine upset conditions and temporary flaring of MEG flash vapours, is expected to meet appropriate standards for human health in the workplace and is not expected to pose a risk of Material or Serious Environmental Harm to the flora, vegetation communities, terrestrial fauna, and subterranean fauna of Barrow Island.

7 Air Quality Management Measures

7.1 Management Measures

As noted in Section 5.1, the results of the air quality modelling studies were used to verify that adequate best practice pollution control measures were identified and implemented in the design of the GTP to minimise emissions (e.g. use of Dry Low NOx burners, MRUs). Where necessary, these studies were also used to identify additional air quality management measures required to further support the implementation of these best practice measures (e.g. development of an Ambient Air Quality Monitoring Program).

Key elements to the success of this Plan are the management measures that have been selected to ensure that the objectives listed in Section 1.4.2 are achieved. Namely, to adequately manage atmospheric pollutant emissions associated with the commissioning, start-up, and operation of the GTP to ensure that air quality meets appropriate standards for human health in the workplace and that air emissions do not pose a risk of Material or Serious Environmental Harm to the flora, vegetation communities, terrestrial fauna, and subterranean fauna of Barrow Island.

Table 7-1 outlines the management measures that will be implemented for each major emission source (see Table 4-1) and other hazardous activities that could potentially result in an emission being generated during the operation of the GTP. Note: The selected management measures include preventive measures, detection systems, control systems, mitigation type measures, and monitoring programs.

Table 7-1: Air Quality Management Measures

Hazard/Activity	Air Quality Management Measure
Exhaust gas emissions from fuel combustion in Frame 9 GTGs	Dry Low NOx burners used
	Low sulfur content in fuel gas
	Fuel gas consumption and composition monitoring
	Preventive maintenance programs to be implemented where appropriate
	MRU within the AGRUs and high-pressure fuel gas system in the Utilities Area
	Ambient Air Quality Monitoring Program
Exhaust gas emissions from fuel combustion in Frame 7 GTs	Dry Low NOx burners used
	WHRUs on Frame 7 GT exhaust stacks
	Low sulfur content in fuel gas
	Fuel gas consumption and composition monitoring
	Preventive maintenance programs to be implemented where appropriate
	MRUs within the AGRUs
	Ambient Air Quality Monitoring Program
Exhaust gas emissions from fuel combustion in Heating Medium Heaters	Low NOx burners used
	Low sulfur content in fuel gas
	Fuel gas consumption and composition monitoring
	Preventive maintenance programs to be implemented where appropriate
	MRU within the AGRUs and high-pressure fuel gas system in the Utilities Area

Hazard/Activity	Air Quality Management Measure
	Ambient Air Quality Monitoring Program
Exhaust gas emissions from fuel combustion in Essential Diesel Power Generators	Run-time monitoring
	Preventive maintenance programs to be implemented where appropriate
	Ambient Air Quality Monitoring Program
Flaring of hydrocarbons and inert gas (nitrogen/hydrocarbon) mixtures through the Wet and Dry Ground Flares	Flare pilot and purge gas only during routine operations
	Radiation shields around ground flares to prevent light spill and thermal radiation effects to surrounding vegetation, personnel, and plant equipment
	Low sulfur content in fuel gas
	MRU within the AGRUs and high-pressure fuel gas system in the Utilities Area
	Ambient Air Quality Monitoring Program
Flaring of hydrocarbons and inert gas (nitrogen/BOG) mixtures through the BOG Flares	Flare pilot and purge gas only during routine operations
	BOG flares (zinc thermal oxidiser flares) used in the storage and loading area
	Low sulfur content in BOG
	BOG and BOG recycle compressors used
	Inert gas/BOG mixture composition monitoring for early diversion to fuel gas system
	MRU within the AGRUs and high-pressure fuel gas system in the Utilities Area
	Ambient Air Quality Monitoring Program
Acid gas venting at the AGRUs and MEG regeneration system	CO_2 Injection System designed to deal with the entire quantity of acid gas separated from the feed gas
	Acid gas vent system designed to facilitate dispersion of vented gas
	Dedicated CO_2 injection unit for each AGRU train
	MRUs within the AGRUs
	Ambient Air Quality Monitoring Program
	MEG flash vapours captured and directed via Condensate Stabilisation system into process stream during routine operations
	Vapours combusted in wet gas flare when Condensate Stabilisation system not available
Fugitive emissions from Condensate Storage Tanks	Material selection and corrosion testing
	Internal floating roof on condensate storage tanks to reduce VOC emission generation
	Preventive maintenance programs to be implemented where appropriate
Fugitive VOC emissions from valves, flanges, pump seals, connectors, diesel storage tanks, etc.	Material selection and corrosion testing
	Preventive maintenance programs to be implemented where appropriate (i.e. Flange Management Program, Leak Detection and Repair Program)
Exhaust emissions from diesel (and marine oil fuel) combustion in temporary diesel generators, infield support vessels (e.g. pilot boats and tugs), and road transport	Use of ultra-low sulfur content diesel fuel
	Diesel fuel consumption monitoring
	Preventive maintenance programs to be implemented where appropriate
	Ambient Air Quality Monitoring Program

Hazard/Activity	Air Quality Management Measure
General GTP Activities	Area gas leak detection used where appropriate
	Area delineation and signage used where appropriate
	Permit to Work system
	Personal protective equipment (PPE) as required by procedures, or as required by the Permit to Work system
	Job Hazard Analyses as required by procedures, or as required by the Permit to Work system
	Commissioning and start-up simultaneous operations (SIMOPS) procedures developed and implemented where appropriate
	Workforce inductions and education packages developed and rolled out where appropriate

8 Performance Objectives and Standards

Environmental performance is 'the measurable results of an organisation's management of its environmental aspects'. CAPL measures environmental performance through:

- **Environmental performance objectives –** the objectives of the Plan as defined by Condition 29 of MS 800
- **Environmental performance standards** – defined, in accordance with Schedule 2 of MS 800, as 'matters which are developed for assessing performance, not compliance, and are quantitative targets or where that is demonstrated to be not practicable, qualitative targets, against which progress towards achievement of the objectives of conditions can be measured'.

Table 8-1 lists the environmental performance objectives and standards that were developed to enable CAPL to assess environmental performance for managing the risk of emissions.

The targets in Table 8-1 were developed specifically for assessing performance, not compliance. Failure to meet the targets does not represent a failure to implement this Plan; rather, it indicates that a performance objective may not have been met and there may be a need for management action or review of the environmental performance objectives and standards.

Table 8-1: Objectives and Performance Standards

No.	Objectives	Performance Standards
1	Ensure air quality meets appropriate standards for human health in the workplace	No exceedance of the National Occupational Health Exposure Standards (see Table 2-3 and Table 2-6).
		No exceedance of the NEPM (Ambient Air Quality) Standards and Goals (see Table 2-1)
		No exceedance of the NEPM (Air Toxics) Monitoring Investigation Levels (see Table 2-2)
		Modelled ambient air quality concentrations of atmospheric pollutants and air toxics not to exceed the applicable assessment criteria for human health during routine and non-routine operating conditions. Actual ambient air quality monitoring results for atmospheric pollutants and air toxics not to exceed predicted (modelled) ambient concentrations of atmospheric pollutants and air toxics during routine and non-routine operating conditions.
2	Ensure air emissions from the GTP do not pose a risk of Material or Serious Environmental Harm to the flora, vegetation communities, terrestrial fauna, and subterranean fauna of Barrow Island	No exceedance of the NEPM (Ambient Air Quality) Standards and Goals (see Table 2-1)
		No exceedance of the NEPM (Air Toxics) Monitoring Investigation Levels (see Table 2-2)
		No exceedance of the Impact Assessment Criteria for Air Toxics (see Table 2-4)
		Modelled ambient air quality concentrations of atmospheric pollutants and air toxics not to exceed the applicable assessment criteria during routine and non-routine operating conditions. Actual ambient air quality monitoring results for atmospheric pollutants and air toxics not to exceed predicted (modelled) ambient concentrations of atmospheric pollutants and air toxics during routine and non-routine operating conditions.
		Modelled nitrogen and sulfur deposition rates to comply with the relevant WHO nitrogen and sulfur deposition criteria as listed in Section 2.3.2

9 Monitoring Program

9.1 Introduction

In the context of this Plan, to achieve the stated objectives, CAPL has developed an Ambient Air Quality Monitoring Program capable of measuring ambient air quality for selected atmospheric pollutants and air toxics for comparison against applicable assessment criteria from:

- NEPM (Ambient Air Quality) Standards and Goals (Ref. 22)
- NEPM (Air Toxics) Monitoring Investigation Levels (Ref. 23)
- National Occupational Health Exposure Standards (Ref. 25)
- NSW DEC Impact Assessment Criteria for Air Toxics and Odorous Air Pollutants (Ref. 31).

This will allow CAPL to establish whether ambient air quality meets suitable key performance standards for human health in the workplace, and whether air emissions from the GTP operations pose a risk of Material or Serious Environmental Harm to the flora, vegetation communities, terrestrial fauna, and subterranean fauna on Barrow Island.

The Ambient Air Quality Monitoring Program considered in the context of this Plan has been designed to be flexible, as the need for ongoing monitoring is expected to be assessed based on the results achieved.

9.2 Monitoring Program Development

As noted in Section 5.1, to assist with the development of the Ambient Air Quality Monitoring Program, air quality modelling work was conducted to assess the potential impacts of atmospheric pollutants and air toxics envisaged to be emitted from all fired equipment, vents, and flares within the GTP in the context of local and regional air quality. The modelling results were used to select the parameters to be monitored, which include NOx, PM_{10}, SO_2, NMVOCs, CO, H_2S, and O_3.

The ambient air quality monitoring locations have been selected based on:

- expected meteorological conditions for Barrow Island (e.g. predominant wind directions)
- proximity to off-site human receptors (e.g. accommodation facilities)
- Barrow Island topography and localised land features, such as steep slopes and gullies
- area of land available to be disturbed, and preference to locate monitoring equipment on previously disturbed areas
- existing and future artificial structures and their potential influence on air movements
- availability of power supply (where needed)
- ensuring compliance with Australian Standard (AS) 3580.1.1:2007 Methods for the Sampling and Analysis of Ambient Air – Guide to the Siting of Air Monitoring Equipment (Ref. 67)
- instrumentation requirements.

The ambient air quality monitoring results are to be used to validate the modelling works; this should provide confidence in the modelling information across Barrow Island for terrestrial and human receptor locations. Conversely, If elevated monitoring results are obtained, CAPL may consider reviewing and changing the relevant air quality management measures or amending the monitoring program, in consultation with DWER, if deemed necessary.

9.3 Monitoring Program Regime

This Section describes the Ambient Air Quality Monitoring Program for the commissioning, start-up and operations phases. This monitoring program is based on the information contained within this Plan.

The baseline data collection component of the Ambient Air Quality Monitoring Program commenced in December 2012. Its aim was to collect monitoring data for a at least 12 months before the commencement of commissioning and start-up activities, so as to obtain a representative set of data for atmospheric pollutant and air toxics baseline levels and to assess their seasonal variations. The Ambient Air Quality Monitoring Program, as outlined in Table 9-1, will continue through the commissioning, start-up and the operations phases of the GTP.

The monitoring information gathered generally includes a description of each monitoring location, the monitoring method (i.e. the equipment to be used), the parameters to be monitored or analysed, and the frequency of the monitoring event.

The monitoring locations shown in Table 9-1 and Figure 9-1 are indicative and may be subject to change to support meeting the objectives listed in Section 1.4.2.

Table 9-1: Ambient Air Quality Monitoring Program

Monitoring Location	Monitoring Equipment[1]	Parameters	Frequency
Butler Park[2] Monitoring Station	Chemiluminescence Analyser (1)	NO NOx NO_2	Continuous[3]
	Tapered Element Oscillating Microbalance (TEOM) (1)	PM_{10}	Continuous[3]
	UV Fluorescence Analyser (2)	SO_2 H_2S	Continuous[3]
	Passive Diffuse Samplers[4] (1)	NMVOC	Continuous (but sample collected fortnightly)
	Gas Filter Correlation/Infra-red (GFC/IR) Analyser (1)	CO	Continuous[3]
	UV Absorption Analyser (1)	O_3	Continuous[3]
	Automated Weather Station (1)	Wind speed and direction Ambient temperature Relative humidity	Continuous[3]
Communications Tower Site[5] Monitoring Station	Chemiluminescence Analyser (1)	NO NOx NO_2	Continuous[3]

Monitoring Location	Monitoring Equipment[1]	Parameters	Frequency
	TEOM (1)	PM_{10}	Continuous[3]
	UV Fluorescence Analyser (2)	SO_2 H_2S	Continuous[3]
	Passive Diffuse Samplers[4] (1)	NMVOC	Continuous (but sample collected fortnightly)
	GFC/IR Analyser (1)	CO	Continuous[3]
	UV Absorption Analyser (1)	O_3	Continuous[3]
	Automated Weather Station (1)	Wind speed and direction Ambient temperature Relative humidity	Continuous[3]
Reference Site - South of the GTP (e.g. at a suitable location near the Barrow Island Airport)	Passive Diffuse Sampler (1)	NMVOC	Continuous (but sample collected fortnightly)
Barge (WAPET) Landing	Passive Diffuse Sampler (1)	NMVOC	Continuous (but sample collected fortnightly)
P36 Well Site	Automated Weather Station	Wind speed and direction Rainfall Ambient and differential temperature Solar radiation Barometric pressure Relative humidity	Continuous[3]
	Passive Diffuse Sampler (1)	NMVOC	Continuous (but sample collected fortnightly)
Relocatable Monitoring Stations[6] Four locations in total (indicative locations depicted in Figure 9-1)	Electrochemical Cell (1) Infra-red (1) Photo Ionisation Detector[7] (1)	H_2S CO_2 NMVOC	Continuous[3]

Notes:

1. *For each type of monitoring equipment, the numbers in brackets represent the total number of monitoring equipment located at the monitoring site.*
2. *A monitoring station was located at Butler Park as this is considered the closest permanent sensitive receptor to the GTP.*
3. *Monitoring data from continuous monitoring equipment is downloaded daily using remote modem access to a data storage server located in Perth.*
4. *This monitoring is for screening exercise purposes only to determine whether additional more rigorous monitoring is required. Depending on the NMVOC monitoring results at the two monitoring stations, there is potential for escalation of NMVOC monitoring from the Passive Diffuse Samplers to either:*
   - *Fourier Transform Infra-red (FTIR) Spectrophotometry, or*

- *Gas Chromatograph with either a Photo Ionisation Detector or Flame Ionisation Detector (GC/FID, GC/PID), or*
- *other open-path analyser.*

5. *A monitoring station will be located at the Communications Tower Site based on technical considerations including air quality modelling, wind direction and proximity to other emissions sources.*
6. *This monitoring is meant as a screening exercise only, so as to determine whether additional more rigorous monitoring is required. The four proposed relocatable monitoring stations are expected to be located in low-lying areas so as to assess any potential impacts to receptors (e.g. fauna) during acid gas venting events. Therefore, the locations of relocatable monitoring stations are subject to change.*
7. *Depending on the NMVOC monitoring results at the four relocatable monitoring stations, there is potential for escalation of NMVOC monitoring from the Photo Ionisation Detector to either:*
   - *Passive Diffuse Samplers, or*
   - *TO-14A Passivated Canisters.*

9.3.1 Ongoing Monitoring Program Maintenance

The ongoing Ambient Air Quality Monitoring Program may be assessed on routine basis (e.g. annually) to ensure the program continues to support CAPL in meeting the objectives listed in Section 1.4.2.

The best mechanism to complete such an assessment is to review the associated monitoring results. For example, if elevated monitoring results are obtained, CAPL may consider changing the monitoring methodology, frequency, location, or associated reporting for a particular parameter. Conversely, consistently low monitoring results may support removal of a parameter or change in monitoring frequency. All such changes would be agreed in consultation with DWER.

9.4 Quality Assurance/Quality Control

Sampling and laboratory analysis quality control includes, as a minimum, trip blanks, field duplicates, and laboratory blanks, in addition to other internal laboratory routine quality control determinations, at frequencies in accordance with accepted AS standards and guidelines.

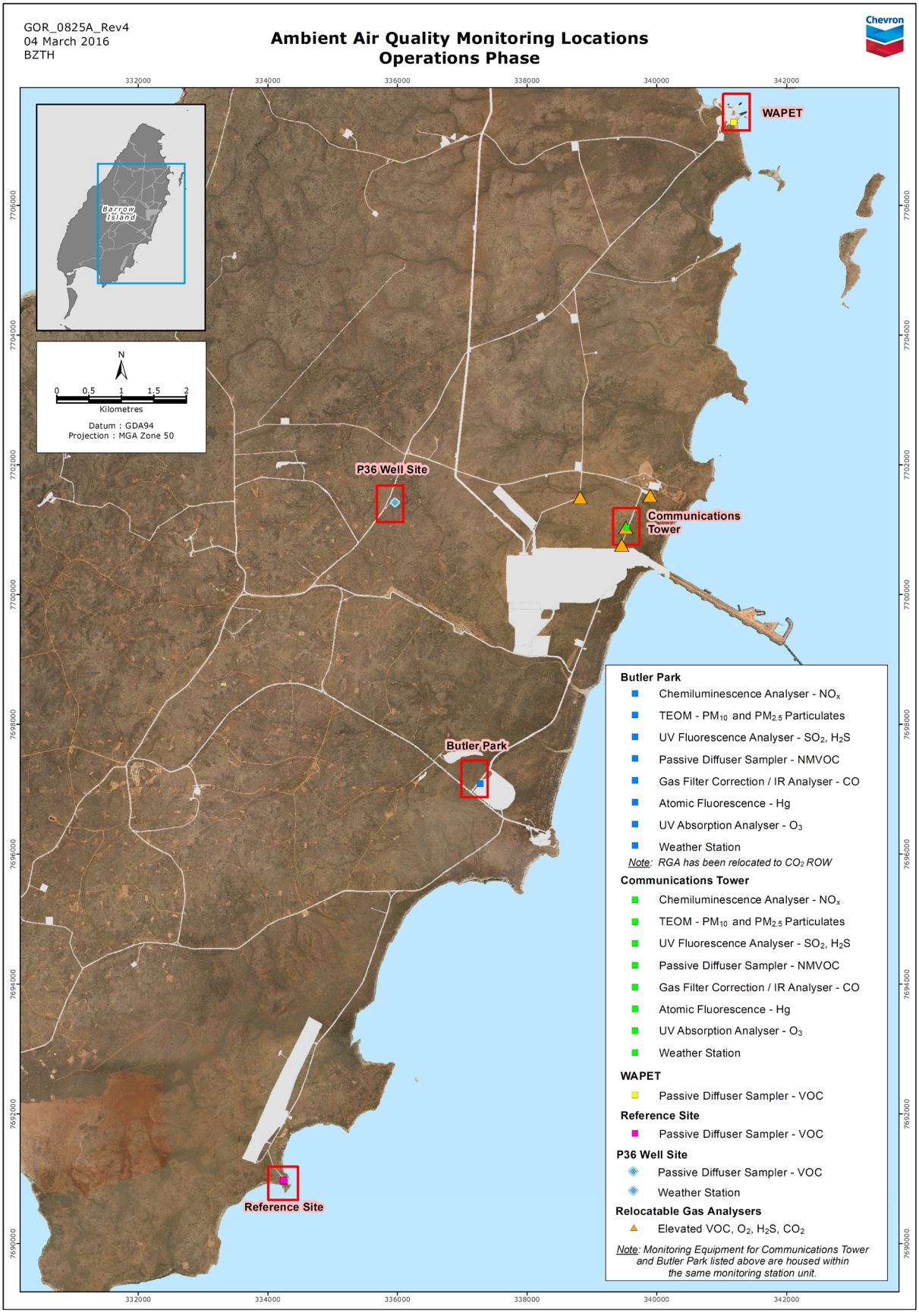


Figure 9-1: Location of Ambient Air Quality Monitoring Sites

10 Acronyms and Abbreviations

Table 10-1 defines the acronyms and abbreviations used in this document.

Table 10-1: Acronyms and Abbreviations

Acronym / Abbreviation	Definition
°C	Temperature in degrees Celsius
µg/m^3	One microgram per cubic metre. 1 µg/m^3 = one millionth of a gram per cubic metre of air, referenced to a temperature of 0 degrees Celsius and an absolute pressure of 101.325 kilopascals.
ABU	Australasia Business Unit
AFAT	Average feed composition, average ambient temperature
AGRU	Acid Gas Removal Unit
Air Toxics	As described in the National Environment Protection (Air Toxics) Measure (Ref. 23) includes benzene, formaldehyde, benzo(a)pyrene (as a marker for polycyclic aromatic hydrocarbons [PAH]), toluene, and xylene (as total of ortho-, meta-, and para-isomers).
Airborne Particles	Particles suspended in the air and existing as aerosols, such as dust, fumes, smoke, or mists.
Ambient Air	As described in the National Environment Protection (Ambient Air Quality) Measure (Ref. 22), ambient air is considered the external air environment, and does not include the air environment inside buildings or structures.
a-MDEA	Activated Methyl Di-ethanol Amine
ANZECC	Australian and New Zealand Environment and Conservation Council
APCI	Air Products and Chemicals Incorporated
ARI	Assessment on Referral Information (for the proposed Jansz Feed Gas Pipeline dated September 2007) as amended or supplemented from time to time.
AS	Australian Standard
ASBU	Australasia Strategic Business Unit
Atmospheric Emissions	Any emission to air, for any period of time, of solid, liquid or gaseous matter. Examples include, but are not limited to, dust and greenhouse gases.
Atmospheric Pollutants	As described in the National Environment Protection (Ambient Air Quality) Measure (Ref. 22) includes carbon monoxide (CO), nitrogen dioxide (NO_2), photochemical oxidants (such as ozone – O_3), sulfur dioxide (SO_2), lead, and particles (such as PM_{10}). In principle, this includes gaseous, aerosol, or particulate pollutants that are present in the air in low concentrations with characteristics such as toxicity or persistence so as to be a hazard to human, plant, or animal life.
BOG	Boil-off Gas; vapours produced because of heat input and pressure variations that occur within various LNG storage and offloading operations.
BPPCDR	Best Practice Pollution Control Design Report
BTEX	Benzene, toluene, ethylbenzene, and xylene aromatic hydrocarbon compounds present in petroleum; may be primary pollutants of soils and groundwater associated with petroleum products.
C_6H_6	Benzene
C_7H_8	Toluene
C_8H_{10}	Ethylbenzene

Acronym / Abbreviation	Definition
CALPUFF	Californian Puff Model
Canary	Proprietary dispersion modelling software
Carbon Dioxide (CO_2) Injection System	The mechanical components required to be constructed to enable the injection of reservoir carbon dioxide, including but not limited to compressors, pipelines and wells..
CB	Carbon Bond
CCR	Central Control Room
CCTV	Closed Circuit Television
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
Construction	Construction includes any Proposal-related (or action-related) construction and commissioning activities within the Terrestrial and Marine Disturbance Footprints, excluding investigatory works such as, but not limited to, geotechnical, geophysical, biological and cultural heritage surveys, baseline monitoring surveys and technology trials.
COPC	Chemical of Potential Concern
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSM	Conceptual Site Model
CTM	Chemical Transfer Model
DAWE	Commonwealth Department of Agriculture, Water and the Environment
DEC	Former Western Australian Department of Environment and Conservation (now DWER)
DER	Former Western Australian Department of Environment Regulation (formerly DEC; now DWER)
DEWHA	Former Commonwealth Department of the Environment, Water, Heritage and the Arts (was SEWPaC; now DAWE)
DMA	Decision Making Authority
DoE	Former Western Australian Department of the Environment (now Department of Biodiversity, Conservation and Attractions)
DomGas	Domestic Gas
DotE	Former Commonwealth Department of the Environment (formerly known as DEWHA then SEWPaC; now DAWE)
Dust	A generic term used to describe fine particles that are suspended in the atmosphere. This term is non-specific with respect to size, shape, and chemical make-up of the particles.
DWER	Western Australian Department of Water and Environmental Regulation (formerly Department of Environment Regulation [DER])
EAD	Equivalent Aerodynamic Diameter. The diameter of a spherical particle of density 1000 kg/m^3 that exhibits the same aerodynamic behaviour as the particle in question.
EIS/ERMP	Environmental Impact Statement/Environmental Review and Management Programme (for the Proposed Gorgon Gas Development dated September 2005) as amended or supplemented from time to time.
EMP	Environmental Management Plan

Acronym / Abbreviation	Definition
Environmental Harm	Has the meaning given by Part 3A of the *Environmental Protection Act 1986* (WA), namely any harm, or potential harm, to the environment (of whatever degree or duration) that is an environmental nuisance.
EP Act	Western Australian *Environmental Protection Act 1986*
EPA	Western Australian Environmental Protection Authority
EPBC Act	Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*
EPBC Reference: 2003/1294	Commonwealth Ministerial Approval (for the Gorgon Gas Development) as amended or replaced from time to time.
EPBC Reference: 2005/2184	Commonwealth Ministerial Approval (for the Jansz Feed Gas Pipeline) as amended or replaced from time to time.
EPBC Reference: 2008/4178	Commonwealth Ministerial Approval (for the Revised Gorgon Gas Development) as amended or replaced from time to time.
EPCM	Engineering, Procurement, and Construction Management
eq/ha/year	'Acid equivalents' per hectare per year
ERA	Ecological Risk Assessment
ETC	Chevron Energy Technology Company
FOB	Freight On Board
FTIR	Fourier Transform Infra-red
g/s	Grams per second
Gas Treatment Plant	Includes the following components: Liquefied Natural Gas (LNG) Trains, LNG Tanks, Gas Processing Drivers, Power Generations, Flares, Condensate Tanks and Utilities Area.
GC/FID	Gas Chromatograph Flame Ionisation Detector
GC/PID	Gas Chromatograph Photo Ionisation Detector
GFC/IR	Gas Filter Correlation/Infra-red
GHG	Greenhouse Gas
GLC	Ground-level Concentration
Gorgon Gas Development	The Gorgon Gas Development as approved under MS 800 and EPBC Reference: 2003/1294 and 2008/4178 as amended or replaced from time to time.
Greenhouse Gases	Components of the atmosphere that contribute to the greenhouse effect, including carbon dioxide (CO_2), methane (CH_4), sulfur hexafluoride (SF_6), and nitrous oxide (N_2O)
GRS	Generalised Reaction Set
GT	Gas Turbine
GTG	Gas Turbine Generator
GTP	Gas Treatment Plant
H_2S	Hydrogen sulfide
ha	Hectare
HES	Health, Environment, and Safety
Hg	Mercury
HRA	Health Risk Assessment

Acronym / Abbreviation	Definition
HSIS	Hazardous Substances Information System
IARC	International Agency for Research on Cancer
IRIS	Integrated Risk Information System
ISO	International Organization for Standardization
Jansz Feed Gas Pipeline	The Jansz Feed Gas Pipeline as approved in MS 769 and EPBC Reference: 2005/2184 as amended or replaced from time to time.
JT	Joule-Thompson
kg	Kilogram
km	Kilometre
kPa	Kilopascal
LNG	Liquefied Natural Gas
LOAEL	Lowest Observed Adverse Effect Level
m	Metre
m^3	Cubic Metre
Material Environmental Harm	Environmental Harm that is neither trivial nor negligible.
MCHE	Main Cryogenic Heat Exchanger
MEG	Monoethylene glycol
mg/cm^2	Milligrams per square centimetre
mg/m^3	Milligrams per cubic metre
MOF	Materials Offloading Facility
Mole %	The ratio of the number of moles of one substance to the total number of moles in a mixture of substances, all multiplied by 100 (to put the number on a percentage basis).
MR	Mixed Refrigerant
MRU	Mercury Removal Unit
MTPA	Million Tonnes Per Annum
MW	Megawatt
N	Nitrogen
N/A	Not Applicable
N_2O	Nitrous oxide
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure for Ambient Air Quality, National Environment Protection Council (NEPC) 26 June 1998 (with additions May 2003)
ng/m^3	Nanograms per cubic metre
NH_3	Ammonia
NMVOC	Non-methane Volatile Organic Compounds
NO	Nitric oxide
NO_2	Nitrogen dioxide
NOAEL	No Observed Adverse Effect Level

Acronym / Abbreviation	Definition
NOx	Nitrogen oxides (NO and NO_2)
NPI	National Pollutant Inventory; an Australian database of certain pollutant emissions reported by industry and managed by the Commonwealth Government.
NSW DEC	New South Wales Department of Environment and Conservation
O_3	Ozone
OE	Operational Excellence
OEHHA	Office of Environmental Health Hazard Assessment
OEMS	Operational Excellence Management System
OH	Hydroxide
Operations (Gorgon Gas Development)	In relation to MS 800 for the respective LNG trains, this is the period from the date on which the Gorgon Joint Venturers issue a notice of acceptance of work under the Engineering, Procurement and Construction Management (EPCM) contract, or equivalent contract entered into in respect of that LNG train of the Gas Treatment Plant; until the date on which the Gorgon Joint Venturers commence decommissioning of that LNG train.
p.a.	Per Annum (per year)
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated biphenyl
PER	Public Environmental Review for the Gorgon Gas Development Revised and Expanded Proposal dated September 2008, as amended or supplemented from time to time.
Performance Standards	Are matters which are developed for assessing performance, not compliance, and are quantitative targets or where that is demonstrated to be not practicable, qualitative targets, against which progress towards achievement of the objectives of conditions can be measured.
PM	Particulate Matter
PM_{10}	Suspended particulate matter consisting of particles having an Equivalent Aerodynamic Diameter (EAD) of less than 10 μm, as defined in Australian Standard (AS) 3580.9.8 (Ref. 68).
$PM_{2.5}$	Suspended particulate matter consisting of particles having an EAD of less than 2.5 μm, as defined in AS 3580.9.13 (Ref. 69).
ppb	Parts per billion
PPE	Personal Protective Equipment
ppm	Parts per million
ppmv	Parts per million by volume
Practicable	For the purposes of MS 800, means reasonably practicable having regard to, among other things, local conditions and circumstances (including costs) and to the current state of technical knowledge.
Revised Proposal	Proposal comprising potential changes to the Approved Gorgon Gas Development as described in the Gorgon Gas Development Revised and Expanded Proposal PER.
RfC	Reference Concentration
RO	Reverse Osmosis
Rsmog	Smog producing reactivity, defined as Volatile Organic Compound (VOC) concentration multiplied by an activity coefficient for smog production.

Acronym / Abbreviation	Definition
s	Second (time)
Sensitive Receptor	Individuals, communities, or components of the environment that could be adversely affected by air or atmospheric emissions; includes dwellings, schools, hospitals, offices, protected wetlands, or public recreation areas that exist now or in the future.
Serious Environmental Harm	Environmental harm that is: irreversible, of a high impact or on a wide scale; or significant or in an area of high conservation value or special significance and is neither trivial nor negligible.
SEWPaC	Former Commonwealth Department of Sustainability, Environment, Water, Population and Communities (formerly DEWHA and DotE; now DAWE)
SF_6	Sulfur hexafluoride
SIMOPS	Simultaneous Operations
SKM	Sinclair Knight Merz
Slug Catcher	A unit in the gas refinery or petroleum industry in which slugs at the outlet of pipelines are collected or 'caught'. A slug is a large quantity of gas or liquid that exits the pipeline.
SO	Sulfur monoxide
SO_2	Sulfur dioxide
SO_3	Sulfur trioxide
SOx	Sulfur oxides
MS 748	Western Australian Ministerial Statement No. 748 (for the Gorgon Gas Development) as amended from time to time [superseded by Statement No. 800].
MS 769	Western Australian Ministerial Statement No. 769 (for the Jansz Feed Gas Pipeline) as amended from time to time.
MS 800	Western Australian Ministerial Statement No. 800 (for the Gorgon Gas Development) as amended from time to time.
MS 865	Western Australian Ministerial Statement No. 865 (for the Gorgon Gas Development) as amended from time to time.
STEL	Short-term Exposure Limit
Subterranean Fauna	Stygofauna: Aquatic below-ground fauna that live in cavities filled with groundwater. Troglofauna: Terrestrial below-ground fauna that inhabit air-filled cavities.
SWA	Safe Work Australia
TAPL	Texaco Australia Pty. Ltd.
TAPM	The Air Pollution Model
TEOM	Tapered Element Oscillating Microbalance, as manufactured by Rupprecht & Patashnick Co. Inc., New York, USA and more recently Thermo, USA.
Terrestrial Disturbance Footprint	The area to be disturbed by construction or operations activities associated with the Terrestrial Facilities listed in Condition 6.3 of MS 800.
Terrestrial Facilities	In relation to MS 800 the terrestrial facilities are the: • Gas Treatment Plant • Carbon Dioxide Injection System • Associated Terrestrial Infrastructure forming part of the Proposal • Areas impacted for seismic data acquisition

Acronym / Abbreviation	Definition
	• Onshore Feed Gas Pipeline System and terrestrial component of the Shore Crossing.
TJ/day	Terajoules of Sales Gas per day
TO-14A	Compendium Method TO-14A, Determination of Volatile Organic Compounds (VOCs) in Ambient Air using Specially Prepared Canisters with Subsequent Analysis by Gas Chromatography, Center for Environmental Research Information, Office of Research and Development (Ref. 70)
TSP	Total Suspended Particulates. Particles that have an equivalent aerodynamic diameter of less than 50 micrometres.
TWA	Time-weighted Average
UF	Uncertainty Factor
UNEP	United Nations Environment Programme
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
VOC	Volatile Organic Compound; organic chemical compounds that have high enough vapour pressures under ambient atmospheric conditions to vaporise and enter the atmosphere.
WA	Western Australia
WAPET	West Australian Petroleum Pty Ltd.
WAPET Landing	Proper name referring to the site of the barge landing existing on the east coast of Barrow Island prior to the date of MS 800.
Wellhead	The surface termination of a wellbore that incorporates systems to provide pressure control, suspension of casing strings, and sealing functionality for oil wells. The primary components are the casing head, casing spools, casing hangers, packoffs and isolation seals, bowl protectors, test plugs, mudline suspension systems, tubing heads, tubing hangers, and tubing head adapters.
WHO	World Health Organization
WHRU	Waste Heat Recovery Unit

11 References

The following documentation is either directly referenced in this document or is a recommended source of background information.

Table 11-1: References

Ref. No.	Description	Document ID
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Appendix A Background Information Supporting the Air Quality Modelling Studies

Background Regional Air Quality

Background regional air quality data were used by SKM to estimate background (pre-Gorgon GTP start-up) air quality on Barrow Island. The following is a general summary of the background regional air quality for the Pilbara Region.

The Pilbara Air Quality Study (Ref. 71) focused on the Burrup Peninsula and the predicted impacts of development on sensitive receptors in the Dampier and Karratha townships. This study identified NOx as one of the most important industrial emissions in the region. In relation to possible health effects, PM_{10} and $PM_{2.5}$ were seen as the most significant air quality issue.

Ambient air monitoring was undertaken for the Pilbara Air Quality Study at Dampier, King Bay, Karratha town site, and Boodarie (Ref. 72). It was found that all measured NO_2 concentrations at Dampier and Karratha were below the NEPM standard for both the maximum one-hour concentration and annual average concentration (Ref. 71). Although within guideline levels, the O_3 concentrations were noted to be well above natural levels (Ref. 71). Physick and Blockley (Ref. 73) noted that the contribution of NOx and VOCs from fires in the Pilbara Region can lead to the enhancement of anthropogenic levels of O_3 and that further investigation into O_3 levels in the area would be warranted.

Monitoring for benzene, toluene, and xylene was undertaken in 2003/2004 at eight sites in Karratha and Dampier using a combination of canisters and ambient diffusion tubes (Ref. 74). Comparison of ambient monitoring results with ambient air concentrations throughout Australia and with national and international standards concluded that ambient exposure to BTEX compounds was no greater for residents of the Burrup Peninsula than for other populations in Australia (Ref. 75).

The Burrup Peninsula Air Pollution Study (Ref. 76), coordinated by the Burrup Rock Art Monitoring Management Committee, reported on ambient air monitoring undertaken from August 2004 to September 2005, to assess the likelihood of damaging effects of air pollution on aboriginal rock etchings in the area. The study measured the concentration of SO_2, NO_2, NO, NH_3, and BTEX gases. Concentrations of all were found to be low when compared to polluted urban areas. An enhancement of NO_2, SO_2, and NO concentrations was found at monitoring sites considered to be representative of industrial locations when compared to those measured at sites assumed to represent background levels.

In its report and recommendations for the Burrup Fertiliser Ammonia Plant (Ref. 77), the EPA noted that the proposed emissions from the plant were small, but that the increasing development in the area will require further research on cumulative impacts. The report also recognised the potential for O_3 to be of increasing concern as the number of industries in the region increases.

Generic Impacts of Key Atmospheric Pollutants and Air Toxics

Pollutant / Air Toxic	Impacts
Oxides of Nitrogen	Potential impacts from NOx exposure on human health include detrimental effects on the human respiratory tract, which could lead to increased susceptibility to asthma and respiratory infections. Potential environmental impacts from NOx exposure include retarded growth rates in vegetation. In addition, elevated levels of NOx that interact with VOCs in the atmosphere could also contribute to O_3 formation or acid rain by the formation of nitrous and/or nitric acid in airborne water droplets. These acid compounds precipitate in rain, snow, and fog, or, in dry form, as gases and particles. The NOx gases and their particulate matter (PM) derivatives may contribute to air quality impacts; e.g. by the acidification of lakes and streams, damage to forest ecosystems, and accelerated decay of building materials (Ref. 33). Nitrogen oxides are also known to contribute to fish kills and algal blooms in waterways (Ref. 78).
Sulfur Dioxide	Sulfur dioxide (SO_2) is a colourless gas with an irritating odour. Potential health impacts from SO_2 exposure could include respiratory illnesses such as asthma or bronchitis. SO_2 has also been linked with the aggravation of existing heart and lung diseases (Ref. 33). Potential environmental impacts from SO_2 exposure include damage to vegetation, ecosystems, monuments, and historic buildings due to the effect SO_2 can have on the formation of acid rain. Acid deposition ('acid rain') occurs when SO_2 reacts with water, oxygen, and other oxidants in the atmosphere to form acidic compounds. These acid compounds precipitate in rain, snow, and fog, or, in dry form, as gases and particles. The SO_2 gases and their PM derivatives may contribute to air quality impacts, e.g. by the acidification of lakes and streams, damage to forest ecosystems, and accelerated decay of building materials (Ref. 33).
Airborne Particulate Matter	Airborne or suspended PM can be defined by its size, chemical composition, or source. Particles can also be defined by whether they are primary particles (e.g. soot particles from incomplete combustion) or secondary particles (e.g. gas to particle conversion of sulfate and nitrate particles from SO_2 and NOx). Airborne particles are commonly classified by their size as Total Suspended Particulate (TSP), visibility-reducing particles (PM_2), and inhalable particles, i.e. coarse fraction (PM_{10}) and fine fraction ($PM_{2.5}$). Potential health impacts from particulate exposure in the PM_{10} size range are associated mainly with exacerbated respiratory problems. The fine fraction ($PM_{2.5}$) particles are strongly implicated as the major influence on the health effects of PM_{10} as they can settle deeper into the lungs. PM can also enhance some chemical reactions in the atmosphere and reduce visibility, especially if the particle size is around 2 microns in size.
Carbon Monoxide	Carbon monoxide (CO) is a colourless, odourless, tasteless, yet highly toxic gas. CO is produced from the partial oxidation of carbon-containing compounds, notably in internal-combustion engines. Potential health impacts from exposure to high levels of CO include paralysis of the central nervous system and heart, resulting in cardiac arrest. Health effects resulting from mild exposure include headaches and dizziness, typically at concentrations less than 100 ppm. CO concentrations in the atmosphere are both short-lived and spatially variable. Although short-lived, CO has an indirect radiative forcing effect by elevating concentrations of methane (CH_4) and tropospheric ozone (O_3) through chemical reactions with other atmospheric constituents (e.g. the hydroxyl radical, hydroxide – OH). Ultimately, CO is oxidised to CO_2.
Ozone	Ozone (O_3) is a colourless gas that is naturally found in the upper atmosphere. O_3 is also formed as a secondary atmospheric pollutant at ground level by the reaction of NOx, VOCs, and sunlight. Photochemical smog is characterised by the reaction of O_3, NOx, and VOCs in sunlight and at high temperatures. A mixture of these chemicals forms a layer of visible, brown or white haze in the sky. Photochemical smog is a regional, and not localised, phenomenon in that O_3 is produced relatively slowly over several hours after exposure to sunlight has been sufficient for the series of reactions to be completed. Therefore, maximum O_3 concentrations tend to occur downwind of the main source areas of precursor emissions, and can become recirculated within local and regional circulation patterns.

Pollutant / Air Toxic	Impacts
	Potential health effects from exposure to O_3 could include irritation of the eyes and throat, and exacerbated existing respiratory problems. Exposure may lead to reduced lung function and may reduce the body's ability to fight respiratory infections. Vegetation exposure to O_3 ranges from visible foliage injury, to growth retardation, and increased sensitivity to stress (Ref. 30). The effects of ground-level O_3 on long-lived species, such as trees, are believed to combine over years so whole forests or ecosystems can be affected.
Volatile Organic Compounds	A wide range of carbon-based molecules are classified as VOCs, including BTEX. VOCs are often divided into two categories—methane and non-methane VOCs (NMVOCs). Potential health impacts from VOC exposure depends on the particular VOC under consideration, e.g. benzene is a carcinogen (see below). In general, most VOCs exhibit some central nervous system effects. Combined with high levels of NOx, VOCs could also contribute to the formation of photochemical smog, which has detrimental effects both on human health and the environment.
Benzene	The following toxicology summary is from the WHO Environmental Health Criteria document on benzene (Ref. 79). In humans, acute exposure to high concentrations of benzene can result in central nervous system depression (headaches, dizziness, and drowsiness), cardiac arrhythmia, respiratory failure, and death. The most significant adverse health effects from short- or long-term exposure to benzene are haematotoxicity (i.e. bone marrow suppression), immunotoxicity, genotoxicity, and carcinogenicity. Benzene has also been shown to induce immunological effects in experimental animals, which are probably a reflection of bone marrow toxicity. Although the relevance of the animal data to human immunological functions has not been established, human immunological alterations have been observed after exposure to benzene. Benzene is a well-established human leukaemogen. There have been numerous epidemiological studies on the effects of benzene, most of which have dealt with chronic industrial exposures. The most consistent evidence for a causal association in humans has been found between benzene exposure and acute myeloid leukaemia.
Toluene	The following toxicology summary is from the WHO Environmental Health Criteria document on toluene (Ref. 80). Toluene is a clear, colourless liquid that is volatile (vapour pressure of 3.82 kPa), flammable, and explosive in air. The general population is exposed to toluene mainly through inhalation of vapour in ambient air, cigarette smoking, and, to a minor extent, by ingestion of food or water contaminated with toluene. Studies on laboratory animals and humans have shown that toluene is readily absorbed from the respiratory tract with an uptake of 40 to 60% in humans. Liquid toluene is also rapidly absorbed through the skin (14 to 23 mg/cm^2 per hour), but absorption from the gastrointestinal tract appears to be slower. Toluene primarily affects the central nervous system. Progressive narcosis and seizures have been seen at high exposure levels (15 000 mg/m^3, 4 hours/day). High doses (>4000 mg/m^3) may induce cardiac arrhythmia. Single, short-term exposures to toluene (750 mg/m^3 for 8 hours) have reportedly caused transient eye and respiratory tract irritation. Repeated occupational exposures to toluene over a period of years at levels of 750 to 1500 mg/m^3 (200 to 400 ppm) have resulted in some evidence of neurological effects.
Ethylbenzene	The International Agency for Research on Cancer (IARC), which is part of the WHO (Ref. 81) listed ethylbenzene as a possible human carcinogen, and California's Environmental Protection Authority and United States EPA (USEPA) have recently listed ethylbenzene as a potential human carcinogen (Ref. 82; Ref. 83). For this reason, the reference toxicity values for ethylbenzene are taken from USEPA's IRIS database, and ethylbenzene is conservatively evaluated as a carcinogen in this health risk assessment. The IARC listed ethylbenzene as a possible human carcinogen, based on chronic cancer studies in rats and mice. USEPA has also adopted a carcinogen-based reference toxicity value for ethylbenzene (Ref. 83).

Pollutant / Air Toxic	Impacts
	The following toxicology summary is excerpted from the WHO Environmental Health Criteria document on ethylbenzene (Ref. 84). Ethylbenzene is a colourless liquid with a sweet gasoline-like odour. It is found in crude oils, refined petroleum products, and combustion products. Ethylbenzene is a non-persistent chemical, being degraded primarily by photo-oxidation and biodegradation. Volatilisation to the atmosphere is rapid. The photo-oxidation reaction of ethylbenzene in the atmosphere may contribute to photochemical smog formation. The log octanol-water partition coefficient is 3.13, indicating a potential for bioaccumulation. However, the limited evidence available shows that ethylbenzene bioconcentration factors are low for fish and molluscs. Elimination from aquatic organisms appears to be rapid. Human exposure to ethylbenzene occurs mainly by inhalation; 40 to 60% of inhaled ethylbenzene is retained in the lungs. Ethylbenzene has low acute and chronic toxicity for both animals and humans. It is toxic to the central nervous system and is an irritant of mucous membranes and the eyes. It is not mutagenic or teratogenic in rats and rabbits. No information is available (in the WHO document) on reproductive toxicity or carcinogenicity of ethylbenzene.
Xylene	The following toxicology summary is excerpted from the WHO Environmental Health Criteria document on xylene (Ref. 85). Xylene is an aromatic hydrocarbon that exists in three isomeric forms: ortho, meta, and para. Xylene is a colourless liquid at room temperature with an aromatic odour. The majority of xylene released into the environment enters the atmosphere directly. In the atmosphere the xylene isomers are readily degraded, primarily by photo-oxidation. Volatilisation to the atmosphere from water is rapid for all three isomers. In soil and water, the meta and para-isomers are readily biodegraded under a wide range of aerobic and anaerobic conditions, but the ortho-isomer is more persistent. The limited evidence available suggests that bioaccumulation of the xylene isomers by fish and invertebrates are low. Elimination of xylene from aquatic organisms is fairly rapid once exposure has ceased. After inhalation exposure the retention in the lungs is about 60% of the inhaled dose. Xylene is efficiently metabolised and does not accumulate significantly in the human body. Acute exposure to high concentrations of xylene can result in central nervous system depression effects and irritation in humans. However, there have been no long-term controlled human studies or epidemiological studies. The chronic toxicity appears to be relatively low in laboratory animals. However, there is suggestive evidence that chronic central nervous system effects may occur in animals at moderate concentrations of xylene. Xylene is not considered to be a mutagen or a carcinogen. The critical end-point is developmental toxicity, which has been demonstrated at an exposure level of 870 mg/m^3 (200 ppm) in rats.
Hydrogen Sulfide	The following toxicology summary is excerpted from the WHO Concise International Chemical Assessment Document on hydrogen sulfide (H_2S) (Ref. 30). H_2S is a colourless gas with a distinctive odour of rotten eggs at low concentrations. It is produced naturally and as a result of human activity. Natural sources include non-specific and anaerobic bacterial reduction of sulfates and sulfur-containing organic compounds. H_2S is found naturally in crude petroleum, natural gas, volcanic gases, and hot springs. Releases to the environment are primarily in emissions to the ambient air, where the chemical is likely to remain for less than one day, but may persist for as long as 42 days in winter. H_2S may evaporate easily from water, depending on temperature and pH. It is unlikely to bioconcentrate and biomagnify in the food chain. Human exposure to H_2S is principally via inhalation, and the gas is rapidly absorbed through the lungs. Most human data are derived from acute poisoning case reports, occupational exposures, and limited community studies. The odour threshold varies depending on the individual; the geometric mean odour threshold is 11 µg/m^3. At concentrations greater than 140 mg/m^3, olfactory paralysis occurs, making H_2S very dangerous, because a few breaths at concentrations around 700 mg/m^3 and greater can be fatal. Short-term inhalation exposure to high concentrations of H_2S causes health effects in many systems; reported health effects in humans following exposure to hydrogen sulfide include death and respiratory, ocular, neurological, cardiovascular, metabolic, and reproductive effects. Respiratory, neurological,

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	and ocular effects are the most sensitive end-points in humans following inhalation exposure. The LOAEL is 2.8 mg/m^3 in asthmatic individuals for respiratory and neurological effects. This LOAEL is used as a basis for the development of a short-term tolerable concentration. Tolerable concentrations for hydrogen sulfide in air of 100 µg/m^3 and 20 µg/m^3, respectively, have been derived based on respiratory effects for short-term (for exposure durations of one to 14 days) and medium-term (for exposure durations of up to 90 days) inhalation exposures. Medium-duration inhalation studies of H_2S in animals have reported respiratory, neurological, and olfactory effects. There are no long-term inhalation studies in animals. The most sensitive target organ for medium-term exposure in animals is the nasal olfactory mucosa; the NOAEL was 14 mg/m^3 (based on rat studies). This NOAEL is used as a basis for the development of a medium-term tolerable concentration. It is not possible to evaluate the carcinogenic potential of hydrogen sulfide, as long-term animal studies are missing and studies on human populations are inadequate. Currently, there is insufficient data available to evaluate the acute toxicity of H_2S on vegetation (Ref. 86).

Appendix B Compliance Reporting Table

Section No.	Key Action	Timing
4.1	Selected emission targets have been specified for major emissions sources where actual point source measurements can be taken safely. For the Gorgon Gas Development, this includes the Frame 9 GTGs, Frame 7 GTs, and Heating Medium Heaters. Table 4-2 lists the emission targets for selected atmospheric pollutants and air toxics emitted from the major emission sources that will be used during the operations phase.	Operations phase
7.1	Table 7-1 outlines the management measures that will be implemented for each major emission source (see Table 4-1) and other hazardous activities that could potentially result in an emission being generated during the operation of the GTP.	All phases
9.3	The Ambient Air Quality Monitoring Program, as outlined in Table 9-1, will continue through the commissioning, start-up and the operations phases of the GTP.	Commissioning, Start-up and Operations phases