REPORT

Central Térmica de Temane Project - Risk Assessment

Moz Power Invest, S.A. and Sasol New Energy Holdings (Pty) Ltd

Submitted to:

Ministry of Land, Environment and Rural Development (MITADER)

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Executive Summary

RISCOM has completed a quantitative risk assessment for the Central Térmica de Temane (CTT) project located in the Inhambane Province, Mozambique to quantify the extent of the impacts on and risks to the surrounding communities posed by the hazardous chemicals to be handled on site. The methodology used is based on the legal requirements of the Netherlands, and the Bevi reference manual for risk assessments developed by the Netherlands National Institute for Public Health and the Environment (RIVM).

It can be concluded from the study that:

- Some of the proposed incidents associated with natural gas, were found to have risks beyond the site boundary of greater than ($1x10^{-6}$ fatalities per person per year) which is an internationally applied measure used to assess risks associated with hazardous chemicals and assess any limitations on land usage to protect vulnerable groups and communities;
- The Identified risks fall into the ALARP range (1 x 10-6 fatalities per person per year to 1 x 10-4 fatalities per person per year) which would be acceptable, with the potential for reduction during detailed engineering. Some mitigation measures have been proposed for consideration by the project;
- These will impact not significantly on the public due to the low population density in the vicinity of the facility and the extent and nature of the impacts, particularly if the land is allocated for industrial use;
- National standards for societal risk in Mozambique have not been identified;

  The methodology used in this assessment is based on the legal requirements of the Netherlands, as outlined in CPR 18E (Purple Book; 1999) and the Bevi reference manual for risk assessments (RIVM (2009)), developed by the Netherlands National Institute for Public Health and the Environment (RIVM). The evaluation of the acceptability of the risks is accessed in accordance with the UK Health and Safety Executive (HSE) ALARP criteria that clearly cover land use, based on the determined risks. The BEVI reference manual is widely used as a guideline for QRAs in many jurisdictions including South Africa.

- The surrounding areas are largely bush/natural vegetation, and there is little evidence on satellite imagery to suggest that the land is inhabited. This has been confirmed by referencing the list of sensitive receptors for the project. It is understood that a 500m partial protection zone (PPZ) would be applied to the site, which would further negate the impacts of hazardous materials on the public. The societal risks for both alternatives would not exceed the threshold value and were not presented;
- A quantitative assessment of the environmental impacts of the various scenarios identified that the impacts would be of low significance (<15) based on the scoring system applied. This can be attributed to the short durations associated with hazardous chemical losses of containment (minutes) compared with those of environmental impacts (years); and
- RISCOM has not found sufficient differentiation between the proposed technology solutions (Closed Circuit Gas Turbine and Open Circuit Gas Engine) based on community safety/quantitative risk assessment to decide either way and have not expressed a specific preference for either technology.

The available information allows a medium confidence level in the assessment. This is based on the information provided being at a detailed conceptual level, which has the potential for changes during implementation and construction. Typically, a high level of confidence would only be assigned based on a review of designs that are finalised for construction. RISCOM did not identify any fatal flaws that would prevent the project proceeding to the detailed engineering phase of the project.

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ACRONYMS

Acronym	Description
AIA	Approved Inspection Authority
ALARP	‘as low as reasonably practicable’
BEVI	**B**esluit **E**xterne **V**eiligheid **I**nrichtingen The Public Safety (Establishments) Decree of the Netherlands
CCGT	Closed Circuit Gas Turbine (Technology Alternative)
CNG	Compressed natural gas (not required in this project)
CPF	Central Processing Facility
CTT	Central Térmica de Temane
EDM	Electricidade de Mozambique E.P.
ESIA	Environmental and Social Impact Assessment
GoM	Government of Mozambique
HEL	Higher explosive limit
ITCZ	Inter-tropical convergence zone
IFC	International Finance Corporation
LEL	Lower explosive limit
LFL	Lower flammable limit
LNG	Liquefied natural gas
MIR	Maximum Individual Risk
MITADER	Ministry of Land, Environment and Rural Development (Ministério da Terra, Ambiente e Desenvolvimento Rural)
MSDS	Material Safety Data Sheet
OCGE	Open Circuit Gas Engine (Technology Alternative)
PAC	Preventative Action Criteria
PADHI	Planning advice for developments near hazardous installations
PPZ	Partial Protection Zone
RIVM	Rijksinstituut voor Volksgezondheid en Milieu The Netherlands National Institute for Public Health and the Environment

Acronym	Description
TOR	Terms of Reference
VCE	Vapour cloud explosion
WB	World Bank

1.0 INTRODUCTION

The Mozambican economy is one of the fastest growing economies on the African continent with electricity demand increasing by approximately 6-8% annually. In order to address the growing electricity demand faced by Mozambique and to improve power quality, grid stability and flexibility in the system, Moz Power Invest, S.A. (MPI), a company to be incorporated under the laws of Mozambique and Sasol New Energy Holdings (Pty) Ltd (SNE) in a joint development agreement is proposing the construction and operation of a gas to power facility, known as the Central Térmica de Temane (CTT) project. MPI's shareholding will be comprised of EDM and Temane Energy Consortium (Pty) Ltd (TEC). The joint development partners of MPI and SNE will hereafter be referred to as the Proponent. The Proponent propose to develop the CTT, a 450MW natural gas fired power plant.

The proposed CTT project will draw gas from either the Sasol Exploration and Production International (SEPI) gas well field via the phase 1 development of the PSA License area, covering gas deposits in the Temane and Pande well fields in the Inhassoro District and the existing Central Processing Facility (CPF) or from an alternative gas source. Consequently, the CTT site is in close proximity to the CPF. The preferred location for the CTT is approximately 500 m south of the CPF. The CPF, and the proposed site of the CTT project, is located in the Temane/Mangugumete area, Inhassoro District, Inhambane Province, Mozambique; and approximately 40 km northwest of the town of Vilanculos. The Govuro River lies 8 km east of the proposed CTT site. The estimated footprint of the CTT power plant is approximately 20 ha (see Figure 1).

Associated infrastructure and facilities for the CTT project will include:

1) Electricity transmission line (400 kV) and servitude; from the proposed power plant to the proposed Vilanculos substation over a total length of 25 km running generally south to a future Vilanculos substation. [Note: the development of the substation falls outside the battery limits of the project scope as it is part of independent infrastructure authorised separately. (although separately authorised, the transmission line will be covered by the Project ESMP, and the Vilanculos substation is covered under the Temane Transmission Project (TTP) Environmental and Social Management Plans). Environmental authorisation for this substation was obtained under the STE/CESUL project. (MICOA Ref: 75/MICOA/12 of 22nd May)];

2) Piped water from one or more borehole(s) located either on site at the power plant or from a borehole located on the eastern bank of the Govuro River (this option will require a water pipeline approximately 11km in length);

3) Access road; over a total length of 3 km, which will follow the proposed water pipeline to the northeast of the CTT to connect to the existing Temane CPF access road;

4) Gas pipeline and servitude; over a total length of 2 km, which will start from the CPF high pressure compressor and run south on the western side of the CPF to connect to the power plant or from an alternative gas source;

5) Additional nominal widening of the servitude for vehicle turning points at points to be identified along these linear servitudes;

6) A construction camp and contractor laydown areas will be established adjacent to the CTT power plant footprint; and

7) Transhipment and barging of equipment to a temporary beach landing site and associated logistics camp and laydown area for the purposes of safe handling and delivery of large oversized and heavy equipment and infrastructure to build the CTT. The transhipment consists of a vessel anchoring for only approximately 1-2 days with periods of up to 3-4 months between shipments over a maximum

15-month period early in the construction phase, in order to offload heavy materials to a barge for beach landing. There are 3 beach landing site options, namely SETA, Maritima and Briza Mar (Figure 7). The SETA site is considered to be the preferred beach landing site for environmental and other reasons; it therefore shall be selected unless it is found to be not feasible for any reason;

8) Temporary bridges and access roads or upgrading and reinforcement of existing bridges and roads across sections of the Govuro River where existing bridges are not able to bear the weight of the equipment loads that need to be transported from the beach landing site to the CTT site. Some new sections of road may need to be developed where existing roads are inaccessible or inadequate to allow for the safe transport of equipment to the CTT site. The northern transport route via R241 and EN1 is considered as the preferred transport route (Figure 8) on terrestrial impacts; however, until the final anchor point is selected, and the barge route confirmed, the marine factors may still have an impact on which is deemed the overall preferable route.

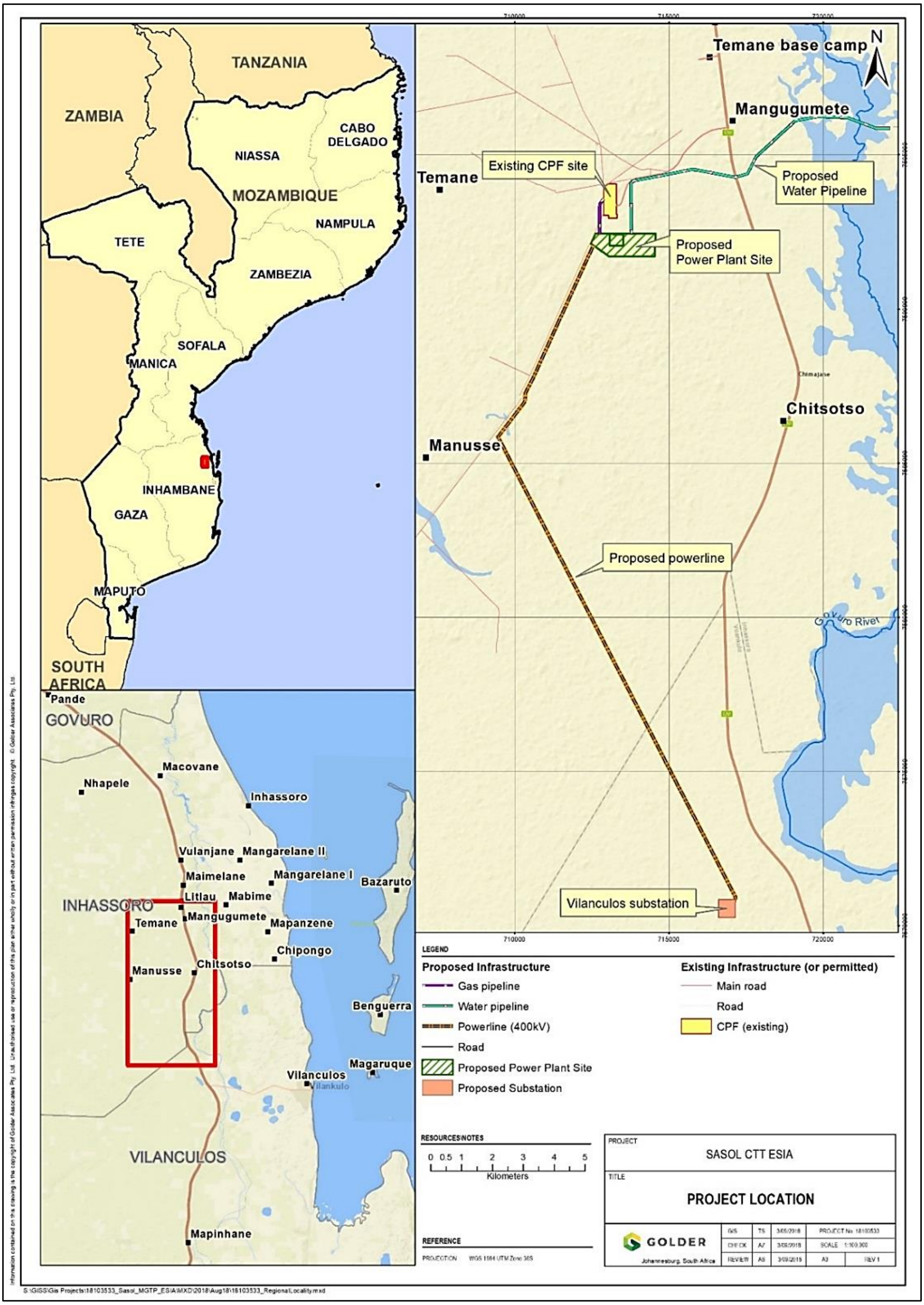


Figure 1: Project Location

2.0 DESCRIPTION OF THE KEY PROJECT COMPONENTS

The CTT project will produce electricity from natural gas in a power plant located 500m south of the CPF. The project will consist of the construction and operation of the following main components:

- Gas to Power Plant with generation capacity of 450MW;
- Gas pipeline (±2 km) that will feed the Power Plant with natural gas from the CPF or from an alternative gas source;
- 400kV Electrical transmission line (± 25 km) with a servitude that will include a fire break (vegetation control) and a maintenance road to the Vilanculos substation. The transmission line will have a partial protection zone (PPZ) of 100m width. The transmission line servitude will fall inside the PPZ;
- Water supply pipeline to a borehole located either on site or at borehole located east of the Govuro River;
- Surfaced access road to the CTT site and gravel maintenance roads within the transmission line and pipeline servitudes;
- Temporary beach landing structures at Inhassoro for the purposes of delivery of equipment and infrastructure to build the power plant. This will include transhipment and barging activities to bring equipment to the beach landing site for approximately 1-2 days with up to 3-4 months between shipments over a period of approximately 8-15 months;
- Construction camp and contractor laydown areas adjacent to the CTT power plant site; and
- Temporary bridge structures across Govuro River and tributaries, as well possible new roads and/or road upgrades to allow equipment to be safely transported to site during construction.

Figure 2: Examples of gas to power plant sites (source: www.industcards.com and www.wartsila.com)

The final selection of technology that will form part of the power generation component of the CTT project has not been determined at this stage. The two power generation technology options that are currently being evaluated are:

- Steam turbines for Combined Cycle Gas Turbine (CCGT); and
- Open Cycle Gas Engines (OCGE).

Please refer to Chapter 4 of the main ESIA document for further details on the technology option.

At this early stage in the project a provisional layout of infrastructure footprints, including the proposed linear alignments is indicated in Figure 1. A conceptual layout of the CTT plant site is shown below in Figure 3.

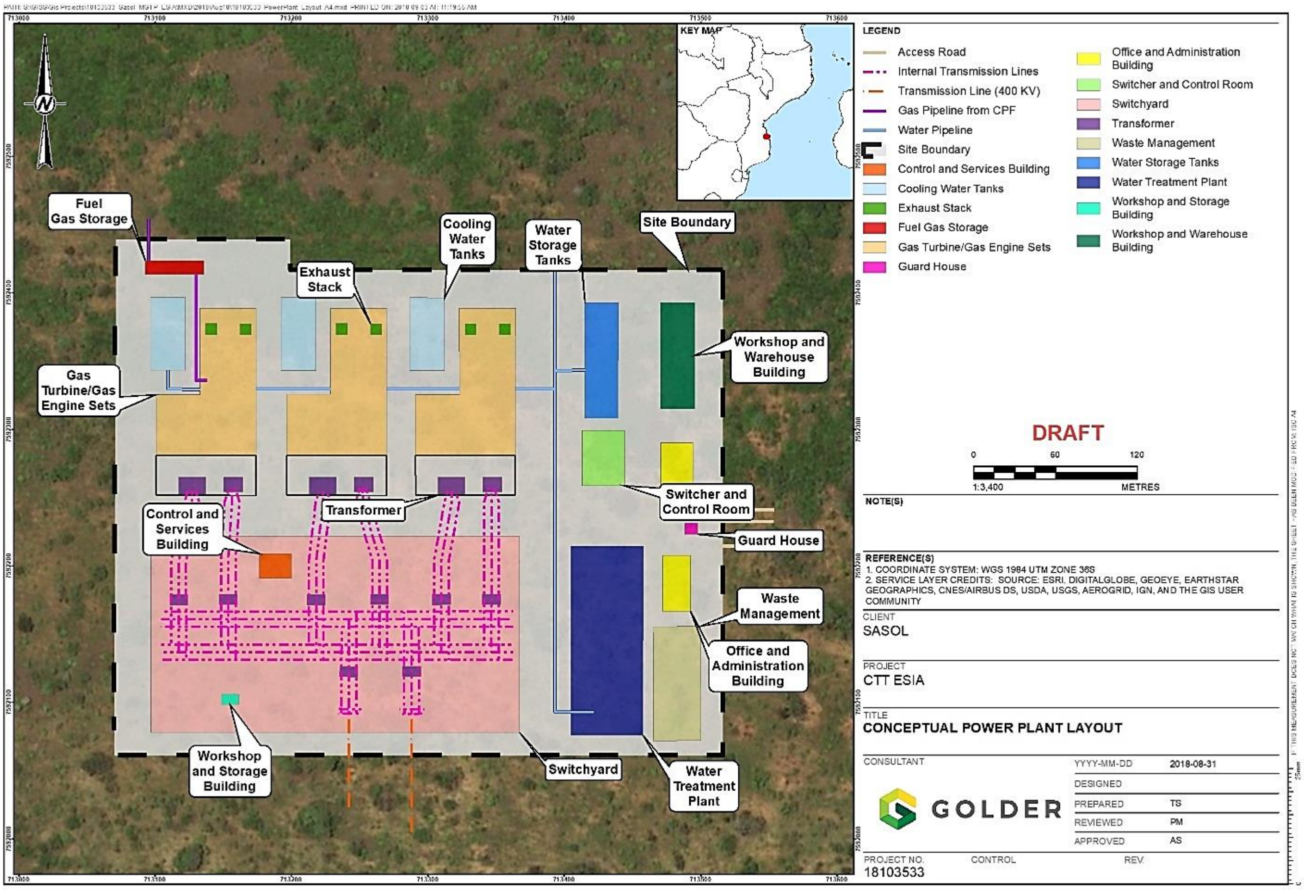


Figure 3: Conceptual layout of CTT plant site

2.1 Ancillary Infrastructure

The CTT project will also include the following infrastructure:

- Maintenance facilities, admin building and other buildings;
- Telecommunications and security;
- Waste (solid and effluent) treatment and/or handling and disposal by third party;
- Site preparation, civil works and infrastructure development for the complete plant;
- Construction camp (including housing/accommodation for construction workers); and
- Beach landing laydown area and logistics camp.

The heavy equipment and pre-fabricated components of the power plant will be brought in by ship and transferred by barge and landed on the beach near Inhassoro. The equipment and components will be brought to site by special heavy vehicles capable of handling abnormally heavy and large dimension loads. Figure 4, Figure 5 and Figure 6 show examples of the activities involved with a temporary beach landing site, offloading and transporting of large heavy equipment by road to site.

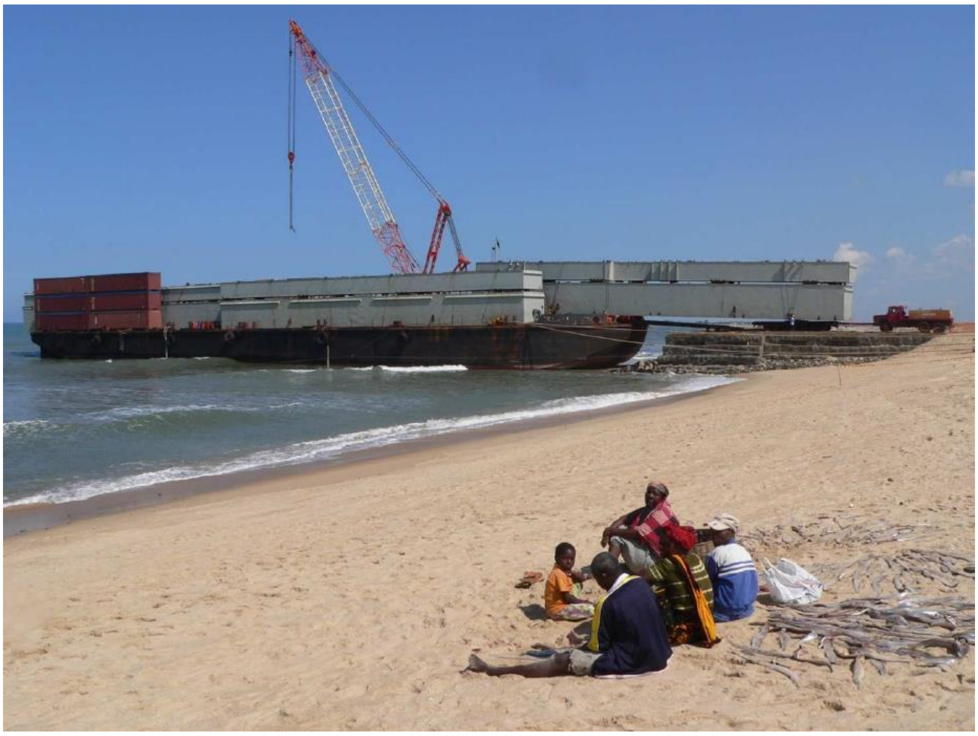


Figure 4: Typical beach landing site with barge offloading heavy equipment (source: Comarco)

Figure 5: Example of large equipment being offloaded from a barge. Note the levels of the ramp, the barge and the jetty (source: SUBTECH)

Figure 6: Heavy haulage truck with 16-axle hydraulic trailer transporting a 360 ton generator (source: ALE)

2.2 Water and electricity consumption

The type, origin and quantity of water and energy consumption are still to be determined based on the selected technology to construct and operate the CTT plant. At this stage it is known that water will be sourced from existing boreholes located on site or east of the Govuro River for either of the technology options below:

- Gas Engine: ± 12 m^3/day; or
- Gas Turbine (Dry-Cooling): ± 120 – 240 m^3/day.

2.3 Temporary Beach Landing Site and Transportation Route Alternative

As part of the CTT construction phase it was considered that large heavy equipment and materials would need to be brought in by a ship which would remain anchored at sea off the coast of Inhassoro. Equipment and materials would be transferred to a barge capable of moving on the high tide into very shallow water adjacent to the beach to discharge its cargo onto a temporary off-loading jetty (typically containers filled with sand) near the town of Inhassoro. As the tide changes, the barge rests on the beach and off-loading of the equipment commences.

Currently, the SETA beach landing site is the preferred beach landing site together with the road route option to be used in transporting equipment and materials along the R241 then the EN1 then via the existing CPF access road to the CTT site near the CPF. Figure 7 and Figure 8 indicate the beach landing site and route transportation option. The alternative beach landing sites of Maritima and Briza Mar are still being evaluated as potential options, as well as the southern transport route, which would also require road upgrades and a temporary bridge construction across the Govuro at the position of the existing pipe bridge. As part of the transportation route, the Govuro River bridge may need to be upgraded / strengthened to accommodate the abnormal vehicle loads. Alternatively, a temporary bypass bridge will be constructed adjacent to the existing bridge.

Figure 7: The three beach landing site options and route options at Inhassoro

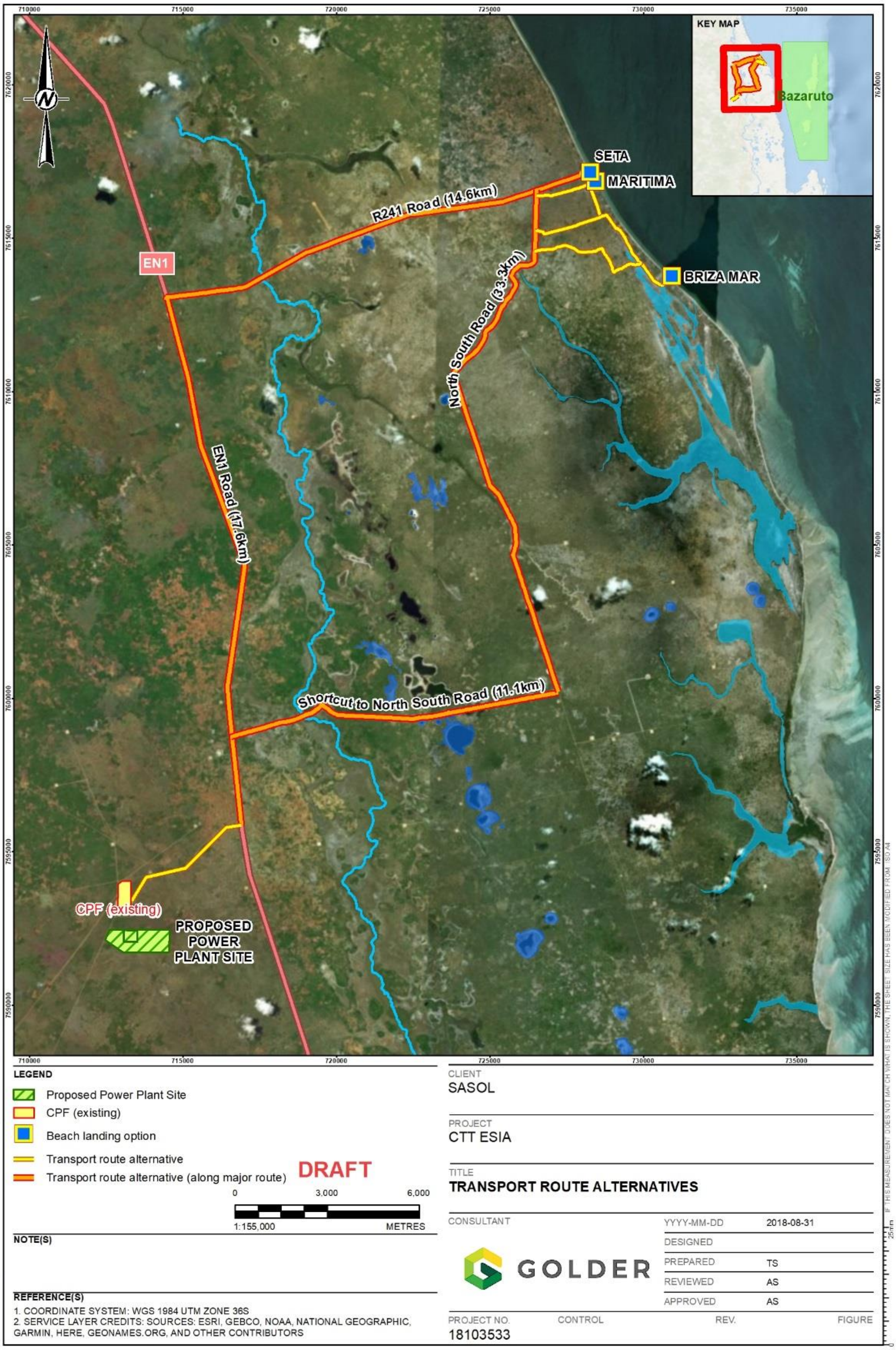


Figure 8: The two main transportation route alternatives from the beach landing sites to the CTT site

Since off-site incidents may result due to the hazards of some of the materials to be stored on or transported onto site, RISCOM (Pty) Ltd was commissioned to conduct a quantitative risk assessment (QRA) to quantify the extent of the impacts on and risks to the surrounding communities. The purpose of this report is to convey the essential details, which include a short description of the hazards, the receiving environment and current relevant design as well as the risks and consequences of a major incident.

At this stage of the project detailed engineering designs are not yet available. The selection of the power generation technology has yet to be finalised and two power generation options are currently being evaluated:

- Combined Cycle Gas Turbine Technology (CCGT, which includes steam turbines);
- Open Cycle Gas Engines (OCGE).

2.4 Terms of Reference (TOR)

This document represents the Quantitative Risk Assessment for the natural gas pipeline and power generation facility, undertaken to support the CTT project ESIA. It has been completed in terms of the environmental legislation of Mozambique, and relevant international standards/guidelines e.g. the World Bank Group operational policies and general environmental health and safety guidelines.

Since off-site incidents may result due to the hazards of some of the materials to be stored on or transported onto site, RISCOM (Pty) Ltd was commissioned to conduct a quantitative risk assessment (QRA) to quantify the extent of the impacts on and risks to the surrounding communities. The purpose of this report is to convey the essential details, which include a short description of the hazards, the receiving environment and current relevant design as well as the risks and consequences of a major incident.

3.0 POLICY, LEGAL AND ADMINISTRATIVE FRAMEWORK

This document represents the Quantitative Risk Assessment for the natural gas pipeline and power generation facility, undertaken to support the CTT project ESIA. It is undertaken in terms of the environmental legislation of Mozambique, as well as the World Bank Group operational policies and general environmental health and safety guidelines. This section contains the details of the legislative framework for the ESIA of the CTT project. The list is not intended to be exhaustive and has been restricted to documents that have a direct relevance to this specialist report.

3.1 National Laws

Mozambique has implemented national legislation to improve the management and protection of the environment, as summarised in Table 1.

Table 1: Summary of Applicable National Environmental Legislation

Legislation	Date of Enactment	Reference	Relevance to this Report
Constitution of the Republic of Mozambique	2004	GoM (2004)	**Article 90. Right to a Balanced Environment** 1. All citizens shall have the right live in a balanced environment and shall have the duty to defend it. 2. The State and the local authorities, with collaboration from associations for environmental protection, shall adopt policies to protect the

Legislation	Date of Enactment	Reference	Relevance to this Report
			environment and shall promote the rational use of all-natural resources.
Environmental Law	Law 20 of 1997 (As amended by Decree 54 of 2015)	GoM (1997)	The project has an environmental impact and will require an Environmental Impact Assessment.
Environmental Impact	Decree 54 of 2015	GoM (2015)	Defines the process and rules to be followed for the project based on it being categorised as Category A.
Quantitative Risk Assessment			No specific legislation regarding the determination methodology for quantitative risk assessment (QRA) has been identified. Refer to Section 3.2.2 regarding the use of the international guidelines.

For 'Category A' projects, an Environmental and Social Impact Assessment (ESIA) must be prepared. The final decision maker is the Ministry of Land, Environment and Rural Development (Ministério da Terra, Ambiente e Desenvolvimento Rural (MITADER) through the National Directorate of Environmental Impact Assessment (DNAIA). MITADER consults with other relevant government departments prior to deciding.

3.2 International Guidelines and Standards

International and standards have been developed to ensure that all project related environmental impacts are identified and managed in a way that is aligned with international best practice.

3.2.1 The World Bank (WB)

The WB has as a Group developed operational policies and safety guidelines for application to projects that are designed, owned, constructed and/or operated by private entities (OP 4.03, WB (2013)), which are based on the International Finance Corporations Performance Standards on Environmental and Social Sustainably (IFC (2012)).

Various project requirements have been identified on the basis of these standards:

3.2.1.1 Standard 4: Community Health, Safety and Security

This standard recognises that project activities, equipment and infrastructure may increase community exposure to risks and impacts and addresses the responsibility of private entities to minimise the impacts to community health, safety and security from a project with particular attention to vulnerable groups. Specific requirements include:

- Evaluation of the risks and impacts to community safety over the lifecycle of the project;
- The design, construction, operation and decommissioning of the project considering the safety risks to third parties and affected communities;

- The avoidance or minimisation of the potential for community exposure to hazardous materials and substances;
- The recognition of the requirement for collaboration with affected communities and in developing emergency responses/preparedness with local authorities.

3.2.2 Quantitative Risk Assessment

Quantitative risk assessments (QRAs) and their associated processes are systematic studies designed to address specific concerns regarding the safety of the public.

Many legislative frameworks lack specific legislation regarding the determination methodology for quantitative risk assessment. The Government of the Netherlands has developed specific risk standards (Bevi decree) for the off-site safety of facilities that require to work with hazardous chemicals in the vicinity of the public. They are aimed at limiting these risks[1] and protecting the public by binding authorities to take legal responsibility for off-site safety, when granting environmental licences and developing land use plans. Risk calculations are required for land use planning and so that risk factors can be properly stipulated in environmental licences.

The methodology used in this assessment is based on the legal requirements of the Netherlands, as outlined in CPR 18E (Purple Book; 1999) and the Bevi reference manual for risk assessments (RIVM (2009)), developed by the Netherlands National Institute for Public Health and the Environment (RIVM). The evaluation of the acceptability of the risks is accessed in accordance with the UK Health and Safety Executive (HSE) ALARP criteria that clearly cover land use, based on the determined risks.

The BEVI reference manual is widely used as a guideline for QRAs in many jurisdictions including South Africa. The specific revision of the Bevi manual used for this Quantitative Risk Assessment in this report is recorded as being 3.2. It is noted that this has been superseded as of 1st July 2015, by revision 3.3 (RIVM 2015), but this is currently only available in the original Dutch.

4.0 RECEIVING ENVIRONMENT

4.1 General Background

The existing Sasol Central Processing Facility (CPF), and the proposed site of the CTT project, are located in the Temane/Mangugumete area, Inhassoro District, Inhambane Province, Mozambique approximately 40 km northwest of the town of Vilanculos. The Govuro River lies 8 km west of the proposed CTT site. The estimated footprint of the CTT is approximately 20 ha and the ESIA study area covers approximately 140 ha.

The preferred location for the CTT gas power plant is approximately 500 m to the south of the CPF as shown in **Figure 9**.

1 BEVI defines risk as the combination of probability and effect (death) as the result of an accident involving hazardous substances. The effects are understood to be acute death as the result of exposure to toxic substances, heat radiation and or overpressures (explosions).

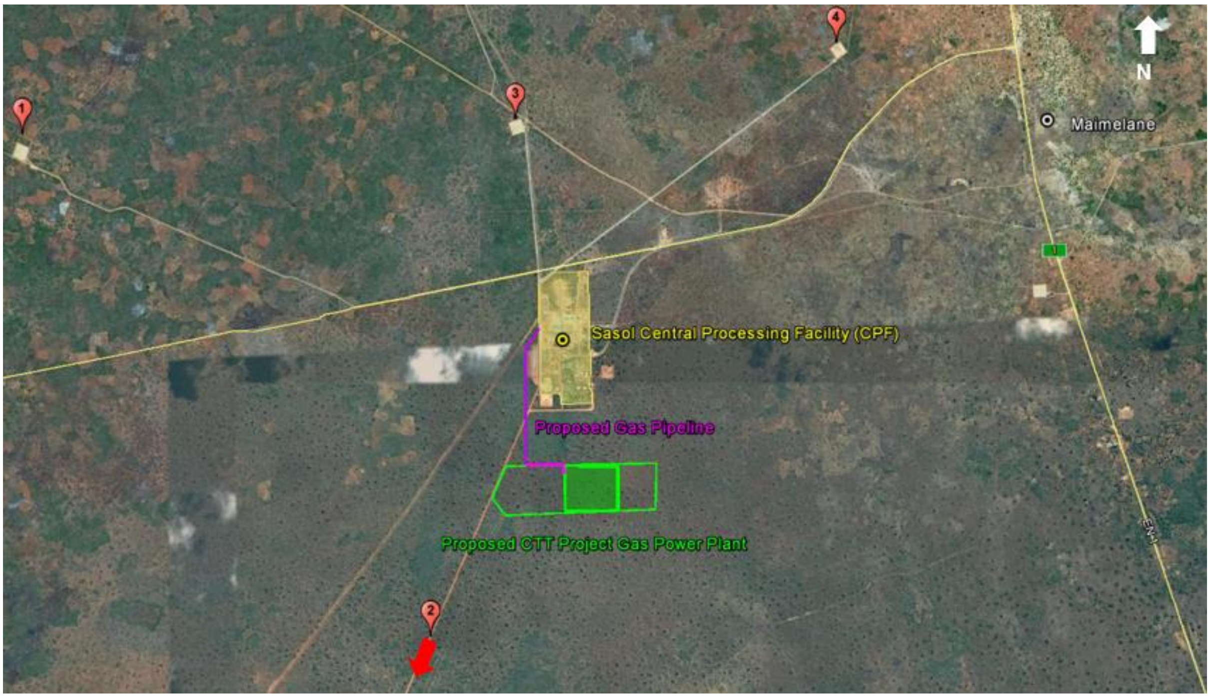


Figure 9: Location of the proposed CTT gas power plant

The population distribution (density) is determined by the low to medium fertility of the soil and low/variable rainfall. Rainfall based "slash and burn" is the principal method of agriculture. The settlement patterns vary from established settlements to mainly scattered populations (low density). Large areas of scrubby bush cover much of the area under consideration.

The land usage around the proposed gas power plant includes:

- To the north, the Sasol Gas Plant separated by approximately 500 m of scrubby bush;
- Underground natural gas pipelines, their associated cut lines and roads radiate from the CPF to well pads (labelled 1 to 4 (2 off page)) located in the surrounding area;
- To the north and north west, the area is covered with natural vegetation with fairly large areas cleared for agriculture;
- To the north-east and east, the village of Maimelane and agricultural land which lies on the EN 1 National Road approximately 4.5 km away;
- To the south and south east, natural vegetation predominates;
- To the west, natural vegetation with fairly large areas cleared for agriculture.

Golder has provided the list of sensitive receptors (Appendix G) used to compile the Air Quality Impact Assessment Report that confirms that the immediate area around the site is unpopulated/unaffected by the presence of sensitive receptors such as households or schools, etc.

4.2 Meteorology

Meteorological mechanisms govern the dispersion, transformation and eventual removal of pollutants from the atmosphere. The extent to which pollution will accumulate or disperse in the atmosphere is dependent on the degree of thermal and mechanical turbulence within the earth's boundary layer. Dispersion comprises vertical and horizontal components of motion. The stability of the atmosphere and the depth of the surface, i.e. the mixing layer, define the vertical component. The horizontal dispersion of pollution in the boundary layer is primarily a function of the wind field. The wind speed determines both the distance of downwind transport and the rate of dilution as a result of *plume stretching*. The generation of mechanical turbulence is similarly a function of the wind speed, in combination with the surface roughness.

The wind directions, and the variability in wind direction, determine the general path pollutants will follow, and the extent of crosswind spreading. Pollution concentration levels therefore fluctuate in response to changes in atmospheric stability, to concurrent variations in the mixing depth and to shifts in the wind field.

The climate of south-eastern Mozambique is controlled by the seasonal north-south movement of the inter-tropical convergence zone (ITCZ) and easterly trade winds from the Indian Ocean. Climatic conditions can be highly variable, and areas can be prone to extreme events such as floods, droughts and cyclones.

The meteorological conditions at Inhassoro/Temane, were provided by Golder and were obtained from the following sources:

- Long-term weather (temperatures, rainfall, etc.) from en.climate-data.org[1];
- Data collected by Sasol at the CPF site for the period January 2013 to December 2017.

4.2.1 Surface Winds

Surface meteorological data, including hourly average wind speed, and wind direction recorded at the CPF, was obtained from Sasol for the period 2013 to December 2017. The wind roses depicted in Figure *10* (Golder (2018)), represent the seasonal variances of the measured wind speeds (dry and wet season).

In the wet season, the wind blows predominantly from the southeast quadrant, at wind speeds typically below 10 m/s. During the dry season, the wind is predominantly from the southwest quadrant, with wind speeds in some instances exceeding 10 m/s.

1 Climate-Model by Climate-Data.org

The \ climate data comes from a climate model. The model has more than 220 million data points and a resolution of 30 arc seconds. The model uses weather data from thousands of weather stations from all over the world. This weather data was collected between 1982 and 2012. This data is refreshed from time to time.

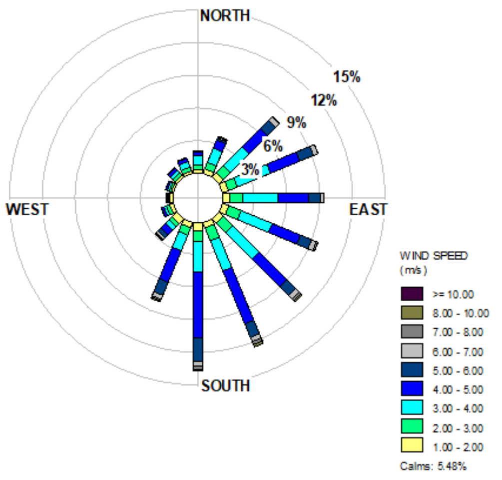
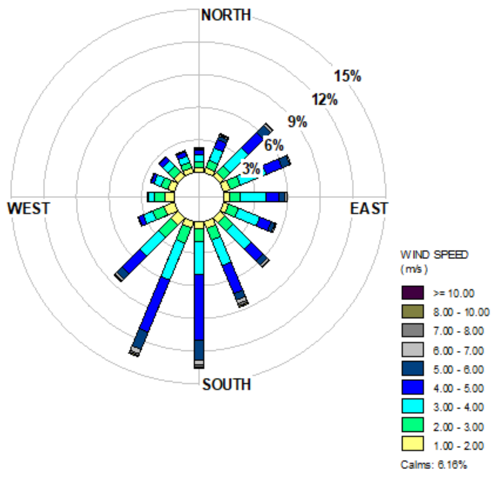
Wet Season (March-December)	Dry Season (April-November)
	

Figure 10: Seasonal wind speed, as a function of wind direction, at the Sasol CPF Temane for the period 2013 to 2017 (Golder (2018))

4.2.2 Precipitation and Relative Humidity

The long-term rainfall at Inhassoro, over the period 1960 - 1991, provided by Golder is given Table 2. Inhassoro shows an average annual rainfall of 836 mm with a dry season between April and November.

Table 2: Long-term modelled rainfall at Inhassoro

Month	Average Monthly Rainfall	Average Daily Relative Humidity
January	156	74
February	150	72
March	122	71
April	48	72
May	30	75
June	26	74
July	18	78
August	22	78
September	13	80
October	21	76
November	75	75
December	155	75
Year	836	76

The relative humidity does not vary appreciably between the seasons. Rainfall in the area is highly seasonal with much less rain falling in the winter months than in the summer months. The difference in precipitation between the driest month and the wettest month is 143 mm.

4.2.3 Temperature

Average monthly temperatures for Inhassoro are contained in Table 3. Over the course of a year, the temperature typically varies from 10°C to 26°C and is rarely below 8°C or above 29°C. The warmest month of the year is January, with an average temperature of 26.7 °C.

The average temperatures vary during the year by 7.3 °C.

Table 3: Long-term temperatures modelled measured at Inhassoro

Month	Temperature (°C)		
	Average Daily mean	**Average Daily Maximum**	Average Daily Minimum
January	26.7	30.9	22.5
February	26.7	31.0	22.4
March	25.5	30.0	21.0
April	24.5	29.6	19.5
May	21.8	27.6	16.1
June	19.9	25.8	14.0
July	19.4	25.4	13.4
August	20.6	26.1	15.1
September	21.9	27.2	16.7
October	24.3	28.7	20.0
November	25.7	29.8	21.6
December	26.3	30.4	22.2
Year	23.6	28.5	18.7

4.2.4 Atmospheric Stability

Atmospheric stability is frequently categorised into one of six stability classes. These are briefly described in Table 4. The atmospheric stability, in combination with the wind speed, is important in determining the extent of a pollutant from a release. A very stable atmospheric condition, typically at night, would have a low wind speed and produce the greatest endpoint for a dense gas. Conversely, a buoyant gas would have the greatest endpoint distance at a high wind speed.

Table 4: Atmospheric stability classification scheme

Stability Class	Stability Classification	Description
A	Very unstable	Calm wind, clear skies, hot daytime conditions
B	Moderately unstable	Clear skies, daytime conditions
C	Unstable	Moderate wind, slightly overcast daytime conditions
D	Neutral	Strong winds or cloudy days and nights
E	Stable	Moderate wind, slightly overcast night-time conditions
F	Very stable	Low winds, clear skies, cold night-time conditions

The atmospheric stability for Sasol CPF, as a function of the wind class, was calculated from hourly weather values measured at the CPF (supplied by Golder) from the 1t January 2013 to the 31 December 2017 and is shown in Figure 11**.**

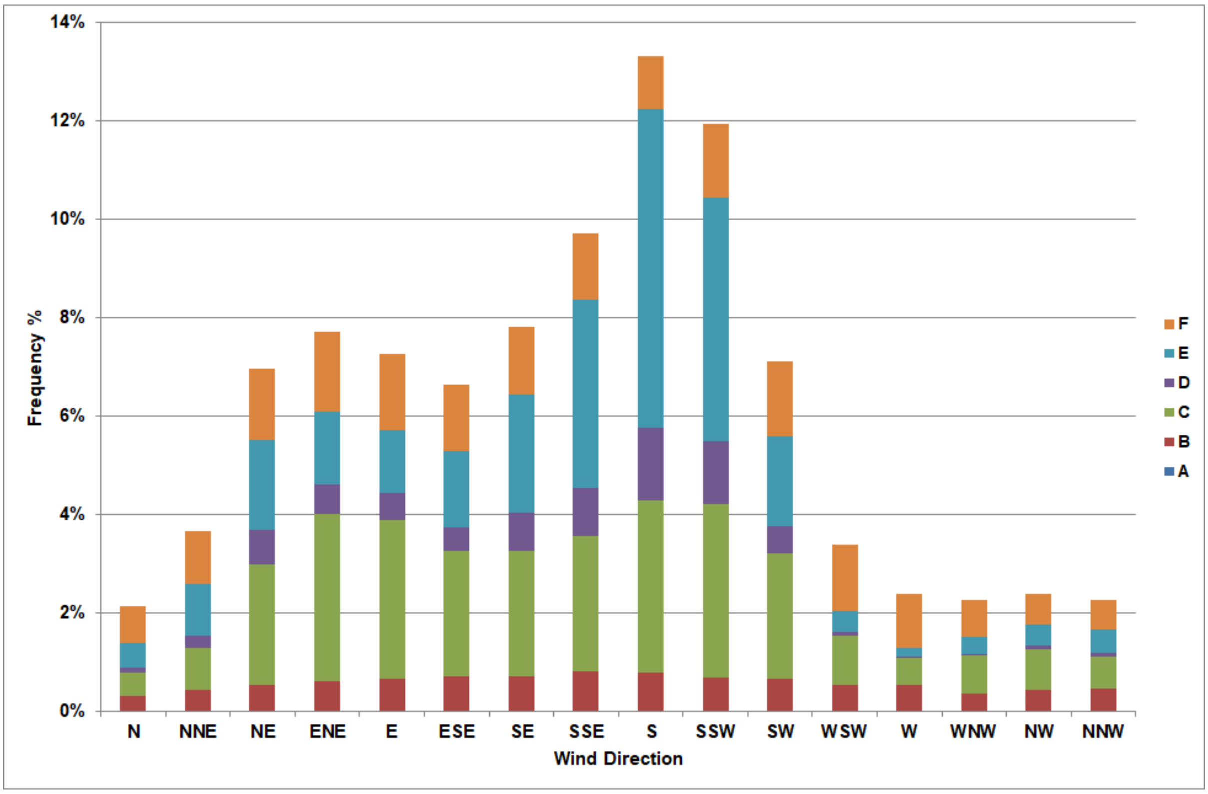


Figure 11: Atmospheric stability as a function of wind direction

Risk assessments are calculated on six representative weather classes covering the stability conditions of stable, neutral and unstable as well as low and high wind speeds. In terms of Pasquill classes, the representative conditions are given in Table 5:.

Table 5: Representative weather classes

Stability Class	Wind (m/s)
B	3
D	1.5
D	5
D	9
E	5
F	1.5

As wind velocities are vector quantities (i.e. have speed and direction) and blow preferentially in certain directions, it is mathematically incorrect to give an average wind speed over the 360°C of wind direction and will result in incorrect risk calculations. It would also be incorrect to base the risk calculations on one wind category, e.g. 1.5/F. In order to obtain representative risk calculations, hourly weather data of wind speed and wind direction were analysed over a five-year period and categorised into the six wind classes for day and night time conditions for 16 wind directions. The risk was then determined using the contributions of each wind class in various wind directions.

The allocation of observations into the six weather classes is summarised in Table 6, with the representative weather classes for the Sasol CPF are given in Figure 12, and used as input for the risk calculations.

Table 6: Allocation of observations into six weather classes

<table>
<tr><th>Wind Speed</th><th>A</th><th>B</th><th>B/C</th><th>C</th><th>C/D</th><th>D</th><th>E</th><th>F</th></tr>
<tr><td><2.5 m/s</td><td colspan="3" rowspan="3">B 3 m/s</td><td colspan="3">D 1.5 m/s</td><td colspan="2">F 1.5 m/s</td></tr>
<tr><td>2.5 - 6 m/s</td><td colspan="3">D 5 m/s</td><td colspan="2">E 5 m/s</td></tr>
<tr><td>>6 m/s</td><td colspan="3">D 9 m/s</td><td colspan="2"></td></tr>
</table>

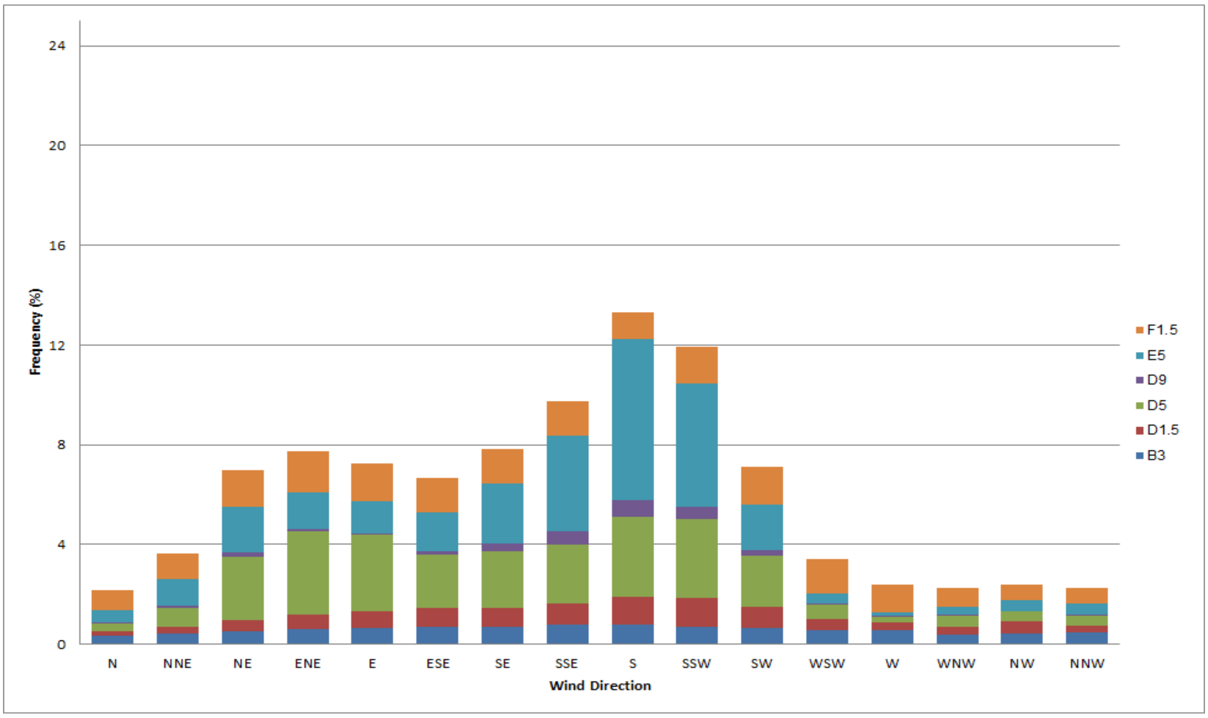


Figure 12: Representative weather classes for Sasol CPF

4.2.5 Meteorological Input Values for Consequence Analysis

The default meteorological values used in the simulation, based on local conditions, values are given below in Table 7.

Table 7: The default meteorological values used in the PHAST simulation, based on local conditions

Parameter	Default Value Daytime	Default Value Night-time
Ambient temperature (°C)	28.5	18.7
Substrate/bund temperature (°C)	23.6	23.6
Water temperature (°C)	23.6	23.6
Air pressure (bar)	1.009	1.009
Humidity (%)	62.8	89.2
Fraction of a 24-hour period	0.5	0.5
Mixing height	[1]	[1]

1 The default values for the mixing height which are included in the model, are 1500 m for weather category B3, 300 m for weather category D1.5, 500 m for weather category D5 and D9, 230 m for weather category E5, and 50 m for weather category F1.5.

5.0 PROCESS DESCRIPTION

The process design basis considered for the purposes of this study is obtained from the two conceptual design reports prepared in 2014 (Foster Wheeler (2014)).

5.1 Site Layout

The CTT project will produce electricity from natural gas in a gas power plant located 500 m south of the existing CPF. Electricity will be produced on a continuous basis for delivery to the national grid.

Various technology options are available for the conversion of thermal energy derived from the combustion of natural gas to electrical power (power island). The two power technology options that are currently being evaluated are:

- Combined Cycle Gas Turbine (CCGT);
- Open Cycle Gas Engines (OCGE).

Final selection of technology that will form the power generation component of the CTT project has not been determined at this stage and is a consideration driving the plant layout. Two conceptual layouts are presented in Appendix C:

- MGTP-F1-PIP-01-01, Rev 2 CCGT Power Plant Preliminary Plot Plan;
- MGTP-F1-PIP-01-02, Rev 1 OCGE Alternative Preliminary Plot Plan.

5.2 Process Schematics

Simplified process flow schematics have been prepared for each of the two options.

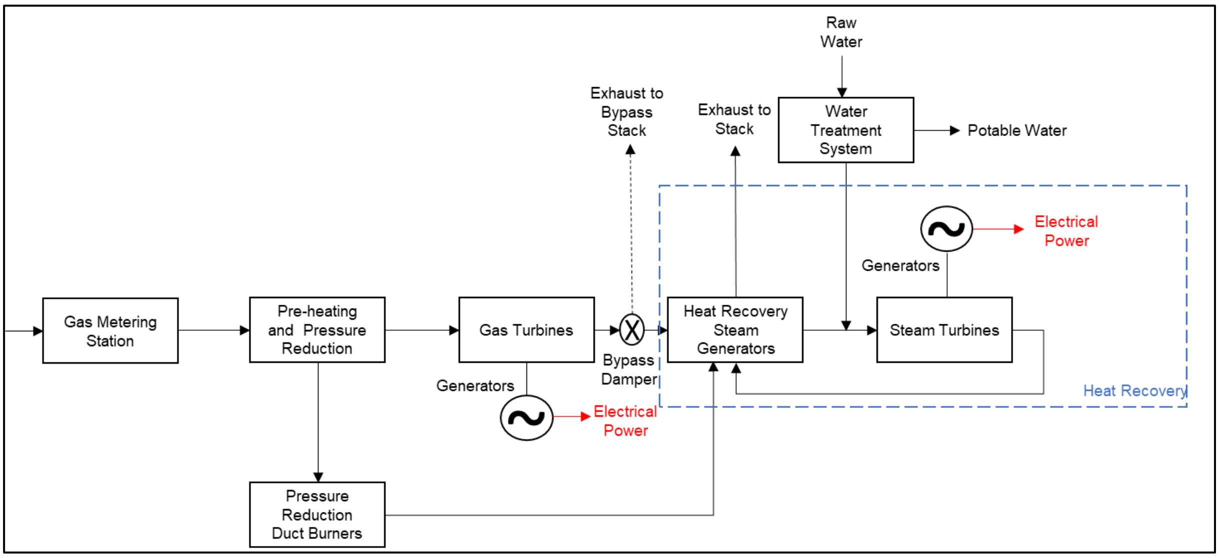


Figure 13: Process Schematic Diagram CCGT Gas Power Plant

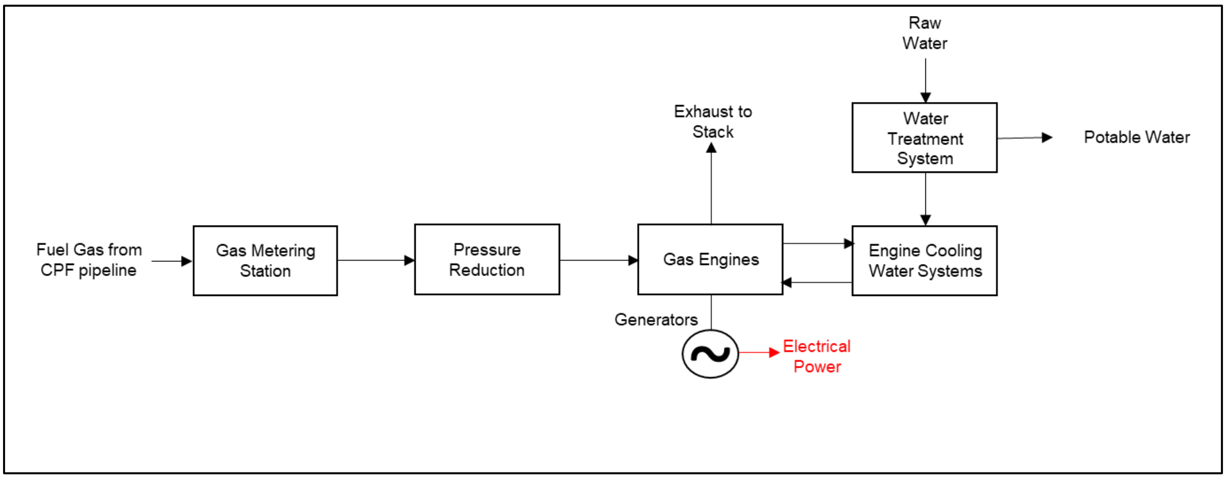


Figure 14: Process Schematic Diagram OCGE Gas Power Plant

The key differences between the two alternatives include:

- The CCGT alternative makes use of gas turbines ("jet engines") whilst the OCGE option makes use of gas engines (internal combustion engines);
- The CCGT alternative makes use of Heat Recovery Steam Generators (HRSG) to raise steam to power a steam turbine for additional energy recovery from the exhaust gases of the gas turbines;
- Hrsgs and Steam Turbines are prone to damage by steam carryover (high solids content) and operate better using "high purity" steam and there is an additional water treatment (chemical dosing) requirement compared to the OCGE alternative.

5.2.1 Natural Gas Pipeline and Fuel Gas System

The natural gas tie-in is at the Central Processing Facility (CPF) upstream of the HP compressor. Natural gas is delivered to the power plant from the CPF through a welded underground pipeline. The natural gas pressure is reduced from the pipeline pressure to suit the requirements of the selected power generation technology.

For both options a 200 mm diameter pipeline approximately 2500 m in length was assumed.

CCGT Fuel Gas Delivery System

The CCGT fuel receiving area consists of a custody metering and preheating section followed by a pressure reducing station ahead of the power plant. Natural gas feed requirements for this alternative are summarized in Table 8.

Table 8: Fuel Gas Feed to Plant CCGT Technology Option

Stream N°·		1	2	3	4
Stream Name		**Fuel Gas Supply**	**Heated Fuel to gas Turbines**	**Heated Fuel to Duct Burners**	**Fuel Supply Single Turbine**
Phase		v	v	v	v
Temperature	**°C**	18	27	27	25
Pressure	**barg**	62.9	30	30	28
Volume Flow	**Nm^3/hr**	77088	69 504	7584	12101
Mass Rate	**kg/hr**	58 907	53 112	5796	9247

OCGE Fuel Gas Delivery System

The CCGT fuel receiving area consists of a custody metering section followed by a pressure reducing station ahead of the power plant. Natural gas feed requirements for this alternative are summarized in Table 9.

Table 9: Fuel Gas Feed to Plant OCGE Technology Option

Stream N°·		1	2	3
Stream Name		**Fuel Gas Supply**	**Heated Fuel to Gas Engines**	**Fuel Supply Single Engine**
Phase		v	v	v
Temperature	**°C**	18	18	25
Pressure	**barg**	62.9	7	5
Volume Flow	**Nm^3/hr**	84636		3852
Mass Rate	**kg/hr**	64 674	64 674	2939

The feed requirements specified in Table 8 and Table 9 have been used to create simulations of the various process scenarios contained in the report.

5.2.2 Combined Cycle Gas Turbine (CCGT) Alternative 1

The combined-cycle gas turbine alternative uses both gas and steam turbines together to produce electricity from the combustion of natural gas supplied from the Sasol CPF. Natural gas is distributed to the gas turbines at ca. 28 barg.

The CCGT circuit described in the conceptual study report consists of three modules, each comprised of the following equipment:

- **2 x Gas Turbines and 2 their generators**

Compressed air is mixed with natural gas injected through nozzles to form an air-fuel mixture, that is combusted to form hot gases that spin the gas turbines, to produce power. The fast-spinning turbines drives the generators that convert a portion of the spinning energy into electricity.

Dry low emission type (DLN) gas turbine burners, operating with or without steam or water injection are used to control emissions.

- **2 x Heat Recovery Steam Generators (HRSG)**

The Heat Recovery Steam Generators (HRSG) capture heat from the gas turbine exhaust gases that would otherwise escape through the exhaust stack. Steam is produced from the hot gas turbine exhaust gases heat and delivered to the steam turbines.

In closed circuit operation, exhaust gases from each turbine enter the respective HRSG at around 600°C or higher and flow counter current across the steam coils which will recover heat from the exhaust gases of the gas turbines. The HRSGs will be of natural circulation type, with horizontal flue gas flow without supplementary firing. Flue gases will be cooled and discharged to the atmosphere at a temperature of about 90 - 110°C though a stack. A continuous emission monitoring system will be in place in order to analyse the exhaust gases' flow rate and components, mainly CO, NO_2, SO_2 and particulates as required by the local Authorities.

Open Circuit Operation

A by-pass stack will also be installed for each of the modules to allow the facility to operate the gas turbines in open cycle mode when the HRSGs or steam turbines are out of service e.g. for maintenance.

- **1 x Condensing Steam Turbine and generator**

The superheated steam (typically around 80 barg) from the HSRGs is expanded in the steam turbine producing mechanical power which is then converted to electric power in the generator coupled to the turbine.

- **1 x Air Cooled Condenser**

The exhaust conditions of the steam turbine typically under vacuum to extract maximum work out of the unit (best efficiency). The exhaust steam/water mixture from steam turbine is fully condensed using an air cooler. The condensate is collected, and a small portion is used as condensing medium for the vacuum system and for the steam turbine gland seal condenser, whilst the majority is recycled to the HRSG.

5.2.3 Open Cycle Gas Engines (OCGE) Alternative 2

Natural gas is combusted in internal combustion engines (ICEs) and the expansion of the hot gases push a piston within a cylinder, which is then converted to the rotation of a crankshaft to produce electrical power. The Power Island in the conceptual study is based on Gas Engine technology and is consists of 24 Gas Engines of approximately 20 MWe size.

The gas engines will be housed in two halls, as shown on the conceptual layout.

Natural gas from the battery limit is heated and sent to each gas engine fuel skid and burner. The gas engines are equipped with water and oil radiator coolers mounted on the engine hall. Lubrication oil is used to primarily lubricate, but also to cool the engines.

Each generating train constitutes a module/genset that includes the engine, the related generator and all required auxiliary systems.

The engine exhaust stacks are ca. 28 m high and bundled together. Each stack will have its own silencer. The exhaust manifold will not be designed to allow for retro coupling to a heat recovery system to generate additional power and increase thermal efficiency.

5.2.4 Balance of Plant

The balance of the gas power plant infrastructure consists of the utilities and services required to support the power generation equipment of the two technology alternatives.

Water Treatment

Raw water is to be supplied to the power generation plants from boreholes by means of pipelines. Various uses are identified for water depending on the requirements of the specific technology employed. A number of water qualities are identified namely:

- Filtered water;
- Potable water;
- Utility water;
- Demineralised water;
- firefighting water.

The volumetric requirement for each type of water is dependent on the technology selected and is summarised in Table 10

Table 10: Water Requirements According to Technology Selected

Water Type	CCGT Technology	OCGE Technology	Difference
Raw water	25.9	3.39	22.51
RO Water (Demineralised Water)	24.18	1.86	22.32
Potable Water	0.41	0.64	-0.23
RO Water to HRSG	20		

The main water use in the OCGE process is for gas engine cooling. Water quality is not as critical for this option as it is with for the closed cycle gas turbine option. The HRSGs and steam turbines are not included in this option and required water quantities are much. The overall water consumption of the CCGT option is significantly higher than that of the OCGE option due to the “clean steam” requirements of the steam turbine and HRSG (condensate makeup).

Chemical Dosing and IX Regeneration

In addition to filtration chemical dosing and IX regeneration are required to achieve the desired water qualities described above, and a number of dosing packages which would include a dosing tank and dosing pumps.

Table 11: Water Treatment Dosing Packages

Reagent	CCGT Technology (kg/hr)	OCGE Technology (kg/hr)	Requirement
Sodium Hypochlorite (NaOCl)	21.4	10.7	Potable water treatment kill bacteria on ultrafiltration membrane
Sulphuric Acid (H_2SO_4)	3.3	1.6	Reverse osmosis feed pH modification. On exchange resin regeneration.
Anti-scalant	1.1	0.6	Reverse osmosis feed
Citric Acid	2.0		Ultrafiltration cleaning in place
Sodium Hydroxide (NaOH)	1.1		On exchange resin regeneration.
Coagulant Dosing	0.65 m^3/hr	0.25	
Polymer Dosing	3	0.25 m^3/hr	
Sodium Meta-Bisulphite			Free chlorine removal RO Feed

Other Plant Utilities

Other plant utilities such as instrument and compressed air are provided for on the site, but do not affect this study.

6.0 BASELINE CONDITIONS

6.1 Scope of study

RISCOM has performed a detailed risk assessment based on incidents that could result in undesirable consequences of fires and explosions resulting from hazardous chemical losses of containment. The scope would include the risk assessment of the technology options under consideration (gas turbines and gas engines) located at the CTT gas power plant site.

The scope considered the construction and operating phases only.

On decommissioning the facility will be deinventorised/drained of all hazardous components as part of the decommissioning and closure plan and will cease to be a hazard to the public, as viewed from the QRA perspective.

6.2 Study methodology

The first step in any risk assessment is to identify all hazards. The merit of including a hazard for further investigation is then determined by how significant it is, normally by using a cut-off or threshold value.

Once a hazard has been identified, it is necessary to assess it in terms of the risk it presents to the employees and the neighbouring community. In principle, both probability and consequence should be considered, but there are occasions where, if either the probability or the consequence can be shown to be sufficiently low or sufficiently high, decisions can be made based on just one factor.

During the hazard identification component of the report, the following requirements are taken into consideration:

- The identities of the various chemicals associated with a site;
- The location of on-site installations that use, produce, process, transport or store hazardous components;
- The type and design of containers, vessels or pipelines;
- The quantity of material that could be involved in a loss of containment;
- The nature of the hazard most likely to accompany hazardous materials spills or releases, is assessed e.g. Natural gas is flammable gas that can give rise to fires (jet and flash fires) or explosions (vapour cloud). The evaluation methodology assumes that the facility will perform as designed in the absence of unintended events such as component and material failures of equipment, human errors, external events and process unknowns.

The determination methodology for this quantitative risk assessment (QRA), is based on the legal requirements of the Netherlands, outlined in CPR 18E (Purple Book; 1999) and the Reference manual for BEVI Risk Assessments (RIVM (2009)). The evaluation of the acceptability of the risks is done in accordance with the UK Health and Safety Executive (HSE) ALAR P criteria that clearly cover land use, based on determined risks.

The specific revision of the BEVI manual used for the Quantitative Risk Assessment in this report is recorded as being version 3.2. It is noted that this has been superseded as of 1st July 2015, by revision 3.3 (RIVM (2015)), but this is currently only available in the original Dutch language.

The QRA process followed in this report is summarised with the following steps:

1) Identification of components that are flammable, toxic, reactive or corrosive and that have potential to result in a major incident from fires, explosions or toxic releases;
2) Development of accidental loss of containment (LOC) scenarios[1] for equipment containing hazardous components (including release rate, location and orientation of release);
3) For each incident developed in step 2, determination of consequences (such as thermal radiation, domino effects, toxic-cloud formation and so forth);
4) For scenarios with off-site consequences (greater than 1% fatality off-site), calculation of maximum individual risk (MIR), considering all generic failure rates, initiating events (such as ignition), meteorological conditions and lethality;
5) Using the population density near the facility, determination of societal risk posed by the facility (if required);
6) Based on the outcomes of the first five steps an environmental impact assessment was conducted to access the environmental significance of the impacts identified.

[1]**Scenario Cut-Off Limits:**

The scenarios included in this QRA have impacts external to the establishment and contribute significantly to an increase the location specific risk. Typically based on the BEVI methodology this means that the only scenarios which satisfy the following criteria need be included in the QRA:

1) The frequency of the scenario is greater than or equal to 1 x 10^{-9} per annum;

2) The 1% fatality from acute affects (thermal radiation, blast overpressure and toxic exposure) is determined as the endpoint (RIVM 2009). Thus, a scenario producing a fatality of less than 1% at the establishment boundary under worst-case meteorological conditions would be excluded from the QRA.

Risk calculations are not precise, and the accuracy of predictions is determined by the quality of base data and expert judgements. This risk assessment included the consequences of fires and explosions as well as toxic releases at the CTT facility in Temane. A number of well-known sources of incident data were used to inform this QRA.

6.2.1 Desktop review of available information

Two conceptual design reports prepared in 2014 (Foster Wheeler (2014)) were used as the basis for the QRA. Additional information was provided by Golder regarding the site and regional meteorological conditions.

6.2.2 Modelling

The site was located at 21°45'2.26"S 35° 3'44.72"E on satellite imagery dated 30/07/2016.

Physical consequences were calculated with DNV's PHAST v. 6.7 and the data derived was entered into TNO's RISKCURVES v. 9.0.26 (when required) to derive the required risk isopleths. All calculations were performed by Mr I.D Ralston. The results derived from the models were then inserted into the satellite image mentioned above to obtain the various graphic representations of the consequence and risk isopleths required for the completion of the study.

A scale and a 100 x100 m have been overlaid on the graphics where possible, for referencing purposes and all are represented with north facing the top of the page.

7.0 HAZARD IDENTIFICATION

The first step in any risk assessment is to identify all hazards. The merit of including a hazard for further investigation is then determined by how significant it is, normally by using a cut-off or threshold value.

Once a hazard has been identified, it is necessary to assess it in terms of the risk it presents to the employees and the neighbouring community.

The evaluation methodology assumes that the facility will perform as designed in absence of unintended events, such as component and material failures of equipment, human errors, external events and process unknowns.

7.1 Substance Hazards

All the components to be applied on the site for each of the two options were assessed for potential hazards according to the criteria discussed in this section.

Natural gas has been identified as potentially the species that has the most dominant off-site risk profile based on power plant feed consumption and the hazards that the gas poses to safety and health.

Preliminary hazardous area classification drawings have been completed and are attached in Appendix C.

- MGTP-F1-PIP-01-02, Rev 0, CCGT Power Plant Preliminary Hazardous Area Classification;
- MGTP-F1-HSE-01-01, Rev 0, OCGE Alternative Preliminary Hazardous Area Classification.

7.1.1 Chemical Properties

A short description of hazardous components to be stored on, produced at or delivered to site is given in the following subsections. Natural gas has been identified as the species that has the most dominant off-site risk profile and the material safety data sheet (MSDS) is attached in Appendix F.

Natural Gas

Natural gas has a high energy density and is cleaner burning than other fossil fuels which makes it a popular fuel choice. Natural gas is a significant fuel source for power generation and will be used as a fuel to power one of the selected equipment alternatives for the CTT.

The composition of natural gas is primarily methane (±95% v/v) with a molecular weight of 16.04 g/mol (lighter than air), together with other components such as ethane, propane and nitrogen. With the exception of nitrogen these are flammable/extremely flammable gases under normal conditions.

Given the flammable and potentially explosive nature of natural gas, fires and vapour cloud explosions (VCEs) represent the primary hazards associated with transfer of the gas. The gas is a fire and explosion hazard when it is exposed to heat and flame. The lower explosive limit (LEL) is 5% v/v (meaning 5% gas to 95% air, measured by volume) and the higher explosive limit (HEL) is 15% v/v. In unconfined atmospheric conditions, the likelihood of an explosion is expected to be small.

It is not compatible with strong oxidants and could result in fires and explosions in the presence of such materials.

It is nontoxic and would be considered as an asphyxiant only. Chronic and long-term effects are low and are not listed.

It is in the gaseous state at atmospheric temperatures and pressures. Economical transportation would require either liquefying or compressing the gas so that it would occupy less volume per weight. Liquefied natural gas (LNG) has a low temperature of -162°C (at atmospheric pressure). The critical pressure of methane is 46 bar; compressed natural gas (CNG) would be above the critical pressure and would be a supercritical gas having a density similar to that of the liquid.

Major Incidents:

There have been a number of incidents associated with natural gas pipelines, the incident described below occurred in a gas power plant environment and highlights the potentially fatal consequences of natural gas pipeline fires/explosions.

On February 7, 2010, an explosion occurred during the commissioning of a gas power plant in Middleton, Connecticut in the United States. The accident occurred during the process of removing debris from piping using natural gas under high pressure ("gas blow"). During the gas blow, it was intended that debris would be expelled through temporary piping cleaning the pipeline, which was a necessary commissioning step for the gas turbines. The temporary piping, instead of being directed vertically upward, was orientated nearly horizontally. Natural gas and debris were expelled horizontally into a confined area in the presence of numerous ignition sources. The ensuing explosion resulted in 6 deaths, more than 50 injuries, massive damage to the project, and significant completion delays.

Water Treatment Chemicals

Treated water is required for potable and process use.

Sodium Hypochlorite (NaClO)

Sodium hypochlorite (NaClO) in water solution is a yellow greenish fluid with a pungent odour and is commonly referred to as 'bleach'. It is not considered toxic or flammable.

It is a powerful oxidising agent and can react violently with possible ignition or explosion with organic materials. In the presence of water, it decomposes releasing oxygen and chlorine. Anhydrous sodium hypochlorite is very explosive. Primary amines and calcium hypochlorite or sodium hypochlorite react to form normal chloramines, which are explosive.

It may be toxic to the lungs, mucous membranes, skin and eyes. Repeated or prolonged exposure can produce target organ damage. Repeated or prolonged contact with a spray mist may produce chronic eye irritation and severe skin irritation. Repeated or prolonged exposure to a spray mist may produce respiratory tract irritation leading to frequent attacks of bronchial infection.

Sulphuric Acid

Sulphuric acid is a colourless substance that may emit choking fumes when hot. It is non-flammable, but when it comes in contact with other flammable materials it may react resulting in fires.

It can have violent reactions with water and strong bases, generating heat. It is not compatible with organic materials, chlorates, carbides, fulminates and powdered metals. In contact with metal, it releases flammable hydrogen gas that will explode if ignited in enclosed spaces.

Sulphuric acid is hazardous for skin contact, inhalation, or ingestion. It is corrosive to the skin, eyes, nose, mucous membranes, respiratory and gastrointestinal tracts or any tissue with which it comes in contact. Severe burns can occur, with necrosis and scarring, and may result in death. Milder exposures can cause irritation of the eyes, skin, mucous membranes and respiratory as well as digestive tracts.

Chronic exposure may be associated with changes in pulmonary function, chronic bronchitis, conjunctivitis and overt symptoms resembling acute viral respiratory tract infection. Discoloration and erosion of dental enamel can occur. Long-term exposure may cause mutations in living cells, bronchitis, emphysema, erosion and pitting of teeth, running nose, upset stomach and tearing of the eyes.

Hydrochloric Acid and Hydrogen Chloride Gas

Hydrogen chloride is a non-flammable colourless gas with a sharp pungent odour. It fumes strongly in moist air and becomes corrosive. Hydrogen chloride is listed by the Environmental Protection Agency (EPA) as an extremely toxic component.

Hydrochloric acid (HCl) is a colourless, acidic and watery liquid with a sharp irritating odour and is commercially available as a solution of up to 38% hydrogen chloride (m/m) dissolved in water.

It reacts exothermically with organic bases (amines and amides) and inorganic bases (oxides and hydroxides of metals). It reacts exothermically with carbonates (including limestone and building materials containing limestone) and hydrogen carbonates to generate carbon dioxide. It reacts with sulphides, carbides, borides and phosphides to generate toxic or flammable gases. It reacts with many metals (including aluminium, zinc, calcium, magnesium, iron, tin and all of the alkali metals) to generate flammable hydrogen gas. Mixtures with concentrated sulphuric acid can evolve toxic hydrogen chloride gas at a dangerous rate.

Hydrogen chloride can be absorbed into the body by inhalation or ingestion. On contact it is corrosive to the eyes, the skin and the respiratory tract. Inhalations of high concentrations are usually limited to the upper respiratory tract and are severe enough to lead to prompt withdrawal. Exposure to the gas causes symptoms such as coughing, burning of the throat and a choking feeling as well as inflammation and ulceration of the nose, throat and larynx. Exposure to higher concentrations, as may occur if a worker is prevented from escaping, may cause laryngeal spasm and oedema of the lungs and vocal cords.

Ingestion of the acid can cause corrosive burns to mouth, throat, oesophagus and stomach. Symptoms may include difficulty in swallowing, intense thirst, nausea, vomiting, diarrhoea and, in severe cases, collapse and death. Small amounts of acid which may enter the lungs during ingestion or vomiting (aspiration) can cause serious lung injury and death.

Long-term exposure to hydrogen chloride has adverse effects on the lungs, resulting in chronic bronchitis. The substance may cause dental discolouration and erosion.

In humans, exposure to 50 – 100 ppm for one hour is barely tolerable. 35 ppm for a short while causes throat irritation, while 10 ppm is tolerable; immediate irritation has been reported at concentrations of over 5 ppm.

7.1.2 Corrosive Liquids

Corrosive liquids considered under this subsection are those components that have a low or high pH and that may cause burns if they come into contact with people or may attack and cause failure of equipment.

The sodium hypochlorite, sulphuric acid, sodium hydroxide and hydrochloric acid used for chemical treatment would be considered highly corrosive.

The corrosive liquids are used for water treatment are dosed in relatively small amounts and are stored sufficiently far from the site boundary that a release would not affect the public.

7.1.3 Reactive Components

Reactive components are components that when mixed or exposed to one another react in a way that may cause a fire, explosion or release a toxic component.

Sodium hypochlorite is unstable and disintegrates when heated.

7.1.4 Flammable and Combustible Components

Flammable and combustible components are those that can ignite and give a number of hazardous effects, depending on the nature of the component and conditions. These effects may include pool fires, jet fires and flash fires as well as explosions and fireballs.

The flammable and combustible components to be stored on, produced at or delivered to site are listed in Table 12. These components have been analysed for fire and explosion risks.

Table 12: Flammable and combustible components to be stored on, produced at or delivered to site

Component	Flashpoint (°C)	Boiling Point (°C)	LFL (vol. %)	UFL (vol. %)
Natural gas	-188	-161	5	15

Gas turbines and engines are often associated with significant anticipated hazards such as fire and explosion, particularly if they are housed in enclosures or rooms. Gas turbines are the subject of a number of international safety codes such as ISO 21789 (ISO (2009)) and Annexure A highlights specific fire explosion hazards associated with gas leaks in turbine enclosures/gas turbine or machine rooms. Specific preventative measures are listed such as:

- High integrity piping;
- Ventilation systems;
- Area classification;
- Electrical isolation of electrical supply;
- Gas detection;
- Fire detection and suppression.

7.1.5 Toxic and Asphyxiant Components

Toxic or asphyxiant components of interest to this study are those that could produce dispersing vapour clouds upon release into the atmosphere.

These could then cause harm through inhalation or absorption through the skin. Typically, the hazard posed by toxic or asphyxiant components will depend on both concentration of the component in the air and the exposure duration.

Nitrogen is used for dissolved air flotation (DAF) for oil recovery from oil contaminated water generated by both technology options. The CCGT option requires nitrogen for the preservation (purging) of the Gas Turbines and Heat Recovery Steam Generators (HRSG's). An unspecified number of nitrogen cylinders are provided in banks for this purpose.

Nitrogen would act an asphyxiants by replacing oxygen and would be potentially hazardous in the GTs and HRSGs during prolonged periods of bypass.

The protective action criteria (PAC) for emergency planning due to toxic releases are given in

Table 13. PAC values are based on the following exposure limit values:

i) The acute exposure guideline level (AEGL) values published by the US Environmental Protection Agency (EPA);

ii) The emergency response planning guideline (ERPG) values produced by the American Industrial Hygiene Association (AIHA);

iii) The temporary emergency exposure limit (TEEL) values developed by the Subcommittee on Consequence Assessment and Protective Actions (SCAPA).

Table 13: Guideline levels for asphyxiant components - nitrogen

Protective Action Criteria	mg/m^3	ppm	Comment
PAC-1	796 000	19.5	*calculated TEEL (60 min) values based on oxygen content contained in the Protective Action Criteria Rev 29 (DOE (2016))
PAC-2	832 000	16	
PAC-3	869 000	12.5	

7.2 Physical Properties

For this study, natural gas was modelled as a pure component, as given in Table 14.The physical properties used in the simulations were based on the DIPPR[1] data base. See Appendix B for the physical and toxicological values used for natural gas in the simulations.

Table 14: Representative components

Component	Modelled as
Natural Gas	Methane

7.3 Components Excluded from the Study

Components excluded from the study are listed in Table 15.

Table 15: Components excluded from the study

Component	Reasons for Exclusion
Sodium hypochlorite	The corrosive liquids are used for water treatment are dosed in relatively small amounts and are stored sufficiently far from the site boundary that a release would not affect the public. The toxic effects of vapours released from sulphuric acid were not considered due its low vapour pressure.
Sulphuric acid	
Sodium hydroxide	
Hydrochloric acid	
Turbine oil	Very high flashpoints making ignition extremely remote.
Lube oils	
Greases	
Diesel for gensets	Site inventories would be very small.
Workshop gases	
Laboratory reagents	

Whilst RISCOM acknowledges the hazards associated with confinements such as turbine enclosures, and machine/turbine halls there is insufficient detailed information to make a meaningful assessment of the quantitative risks associated with this type of hazard (indoor release). The type of study should form part of the detailed engineering of the project.

8.0 PHYSICAL AND CONSEQUENCE MODELLING

In order to establish which impacts could follow an accident, it is first necessary to estimate the physical process of the spill (i.e. rate and size), spreading of the spill, evaporation from the spill, subsequent atmospheric dispersion of the airborne cloud and, in the case of ignition, the burning rate and resulting thermal radiation from a fire and the overpressures from an explosion.

The second step is then to estimate the consequences of a release on humans, fauna, flora and structures in terms of the significance and extent of the impact in the event of a release. The consequences could

1Design Institute for Physical PRoperties be due to toxic or asphyxiant vapours, thermal radiation or explosion overpressures. They may be described in various formats.

The simplest methodology would show a comparison of predicted concentrations, thermal radiation or overpressures to short-term guideline values.

In a different but more realistic fashion, the consequences may be determined by using a dose-response analysis. Dose-response analysis aims to relate the intensity of the phenomenon that constitutes a hazard to the degree of injury or damage that it can cause. Probit analysis is possibly the method mostly used to estimate probability of death, hospitalisation or structural damage. The probit is a lognormal distribution and represents a measure of the percentage of the vulnerable resource that sustains injury or damage. The probability of injury or death (i.e. the risk level) is in turn estimated from this probit (risk characterisation).

Consequence modelling gives an indication of the extent of the impact for selected events and is used primarily for emergency planning.

A consequence that would not cause irreversible injuries would be considered insignificant, and no further analysis would be required. The effects from major incidents are summarised in the following subsections.

Natural gas is transferred from the CPF to the CTT using pressurized pipelines. The Bevi manual defines two specific scenarios that are required to be considered for all process piping, namely:

- Rupture of the pipeline (full bore);
- Leaks with a diameter of up to 10% of the nominal diameter of the pipeline (to a maximum of 50 mm).

Each of these events may for natural gas give rise to the multiple consequences described in Section 8.1.

8.1 Multiple Consequence Scenarios

Guidelines for selection of scenarios is given in RIVM (2009) and CPR 18E (Purple Book; 1999). A particular scenario may produce more than one major consequence. In such cases, consequences are evaluated separately and assigned failure frequencies in the risk analysis. Some of these phenomena are described in the subsections that follow.

8.1.1 Continuous Release of a Flammable Gas

The continuous loss of containment of a flammable gas could result in the consequences given in the event tree contained in Figure 15. The probability of the events occurring is dependent on a number of factors and is determined accordingly. All the scenarios shown in the figure are determined separately and reported in relevant subsections of the report.

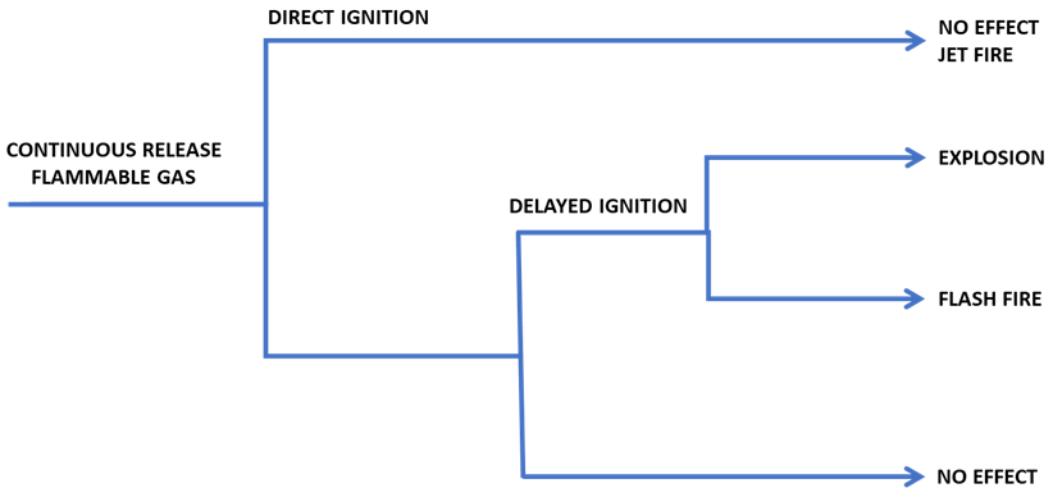


Figure 15: Event tree for a continuous release of a flammable gas (RIVM (2009))

Combustible and flammable gases such as natural gas, may within their flammable limits ignite and burn if exposed to an ignition source of sufficient energy. On process plants releases with ignition normally occur as a result of a leakage or spillage.

Natural gas is used as a fuel for the electricity generation technologies that have been considered (gas turbines and gas engines), can depending on the operating parameters give rise to jet fire, flash fire and delayed explosions.

Key operating parameters that will affect the impacts of a release of natural gas from pipelines include:

- The nature of the release (continuous or instantaneous), pipeline ruptures and leaks occur over time and are modelled as continuous releases;
- The location of the release;
- The orientation of the release, bevi assumes vertical release for underground pipes and horizontal for aboveground pipes;
- The operating temperature and pressure of the gas;
- The size of the release. The ignition frequency is determined by the size of release (appendix d,
- Table 13), continuous releases of the order of 10 kg/s and below are at the lower end of the process flowrates considered for a continuous release.
- Various leak scenarios were simulated but were found to have fairly small consequences, typically less than 10 m, which did not satisfy the limits for inclusion in the QRA (1% fatality did not extend beyond the plant boundary).

8.2 Fires

Combustible and flammable components within their flammable limits may ignite and burn if exposed to an ignition source of sufficient energy. On process plants releases with ignition normally occur as a result of a leakage or spillage. Depending on the physical properties of the component and the operating parameters, combustion may take on a number of forms, such as pool fires, jet fires, flash fires and so forth.

Thermal Radiation

The effect of thermal radiation is very dependent on the type of fire and duration of exposure. Certain codes, such as the American Petroleum Institute API 520 and API 2000 codes, suggest values for the maximum heat absorbed by vessels to facilitate adequate relief designs in order to prevent failure of the vessel. Other codes, such as API 510 and the British Standards BS 5980 code, give guidelines for the maximum thermal radiation intensity and act as a guide to equipment layout, as shown in

The effect of thermal radiation on human health has been widely studied, relating injuries to the time and intensity of exposure.

Table 16: Thermal radiation guidelines (BS 5980 of 1990)

Thermal Radiation Intensity (kW/m^2)	Limit
1.5	Will cause no discomfort for long exposure
2.1	Sufficient to cause pain if unable to reach cover within 40 seconds
4.5	Sufficient to cause pain if unable to reach cover within 20 seconds
12.5	Minimum energy required for piloted ignition of wood and melting of plastic tubing
25	Minimum energy required to ignite wood at indefinitely long exposures
37.5	Sufficient to cause serious damage to process equipment

For pool fires, jet fires and flash fires CPR 18E (Purple Book; 1999) suggests the following thermal radiation levels be reported:

i) 4 kW/m^2, the level that glass can withstand, preventing the fire entering a building, and that should be used for emergency planning;

ii) 10 kW/m^2, the level that represents the 1% fatality for 20 seconds of unprotected exposure and at which plastic and wood may start to burn, transferring the fire to other areas;

iii) 35 kW/m^2, the level at which spontaneous ignition of hair and clothing occurs, with an assumed 100% fatality, and at which initial damage to steel may occur.

Natural gas is a flammable gas that is proposed for use as a fuel for both the gas turbines (technology alternative 1) and the gas engines (technology alternative 1. It is delivered to site via an underground pipeline from the Sasol CPF which is situated 500 m north of the site.

A loss of containment could occur due to a rupture or leak associated with the underground pipeline or the process piping inside the gas power plant (RIVM (2009)).

8.2.1 Jet Fires

Jet fires occur when a flammable a component is released with a high exit velocity ignites.

The properties of jet fires depend on the fuel composition, release conditions (temperature and pressure), release rate, release geometry (vertical or horizontal), direction and ambient wind conditions.

In the process industries this may be due to design (such as flares) or due to accidental releases. Ejection of a flammable component from a vessel, pipe or pipe flange may give rise to a jet fire and in some instances the jet flame could have substantial ‘reach’.

Depending on wind speed, the flame may tilt and impinge on other pipelines, equipment or structures. The thermal radiation from these fires may cause injury to people or damage equipment some distance away from the source of the flame.

8.2.1.1 CPF to CTT Underground Gas Pipeline

Underground pipelines are modelled as occurring at the surface (0 m) with a vertical orientation. Vertical jet fires impinge on the ground less than those that are horizontal, and their momentum is less constrained. Simulations of vertical jet fires indicate that for similar release conditions a vertical jet fire will have reduced effects compared with a horizontal. This can be explained as follows:

- The flames are vertical with a lower thermal radiation view factor reducing the extent of the thermal radiation impact;
- Horizontal jet fires potentially have a larger flame footprint in contact with the ground than their vertical counterparts, contact with the flames typically results in 100% fatalities.

The 10 kW/m^2 thermal radiation isopleths, representing the 1% fatality under high wind speed conditions has been used to compare the two different flow scenarios for the two the two technologies as shown in Figure 16 and they illustrate relatively similar footprints. The larger circles represent the cumulative consequences from all wind directions, whilst the smaller ones represent the consequence from a northerly wind condition.

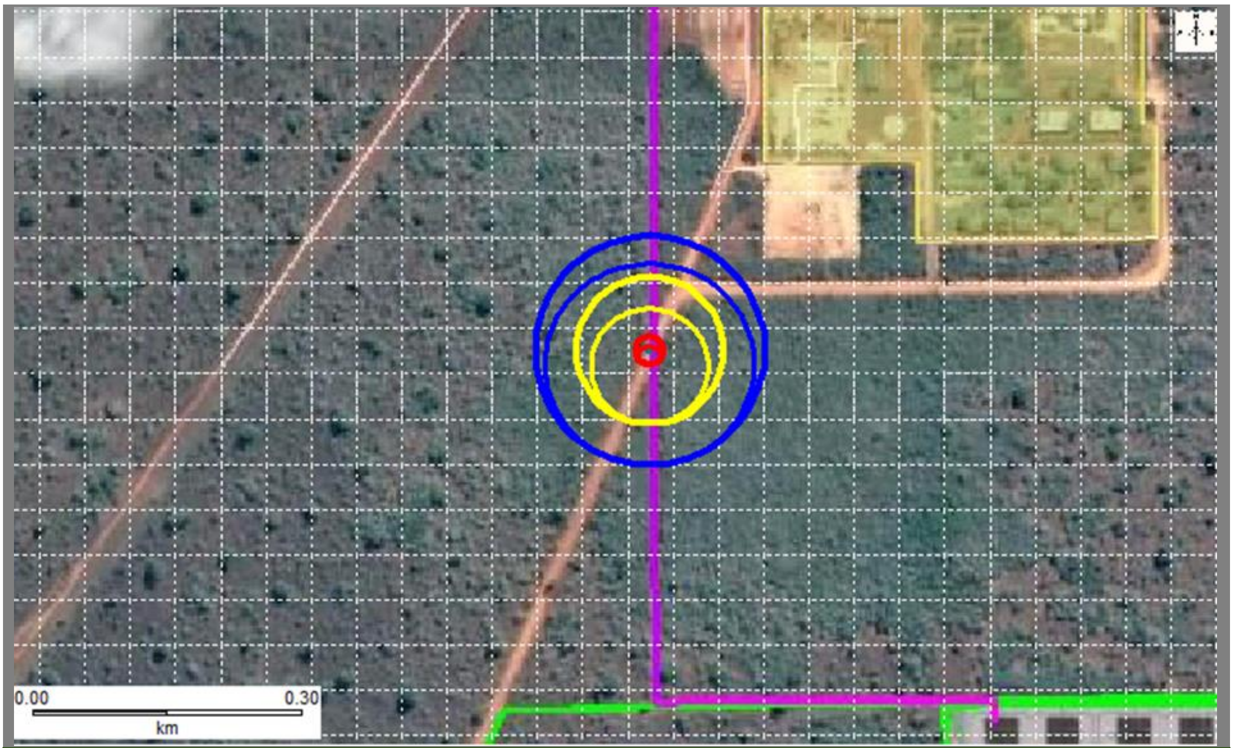
While fatalities could be expected to occur within the1% fatality isopleth, the surrounding area is naturally vegetated bush or sparsely populated reducing the probability of fatalities.

LEGEND	SCENARIOS (1% Fatality, 10 kW/m²)
(red line)	CCGT, Alternative 1 (200 mm, pipeline rupture)
(yellow line)	OCGE Alternative 1 (200 mm, pipeline rupture)

Figure 16: 10 kW/m^2 Thermal radiation isopleths for releases from the CPF/CTT u/g pipeline scenarios

The 4, 10 and 35 kW/m^2 for Alternative 2 have been calculated and are represented in Figure 17. These are of interest from the following perspectives:

- The 4 kW/m^2 is capable of breaking glass and is the lower limit in emergency planning for escape routes.;
- The 10 kW/m^2 is the value for 1% fatality for unprotected people, with exposure duration at 20 seconds. It is not anticipated that the CPF will be affected;
- The 35 kW/m^2 represents the radiation limit for spontaneous combustion of hair and clothing, with a 100% fatality and is close to the 37 kW/m^2, which represents initial damage to metal equipment.



LEGEND **SCENARIOS (1% Fatality, 10 kW/m^2)**

CCGT, Alternative 1 (200 mm, pipeline rupture)
OCGE Alternative 1 (200 mm, pipeline rupture)

Figure 17: Isopleths representing worst case thermal radiation from a natural gas jet fire (Alternative 1)

8.2.1.2 CTT Gas Power Plant

Various jet fires scenarios resulting from full bore ruptures of aboveground process pipes (horizontal release) were simulated at various points in the fuel supplies to the turbines/engines.

Figure 18 (Alternative 1) and Figure 20 (Alternative 2) depict the 1% lethality from jet fires under strong wind conditions, as represented by the 10 kW/m^2 thermal radiation for these scenarios. The thin lines indicate the orientation of the release, while the thicker lines indicate the *effect zone* with a flame from all orientations.

The incoming feed line to the plant (high pressure) represented by the red isopleth in both cases presents the largest effect zone in both cases extending slightly more than 100 m beyond the site boundary (100 m square grid) in the worst case (Alternative 1 CCGT). The potential is created for fatalities that extend beyond the site boundaries and must be carried over to the risk assessment. Impingement of the flash fires onto the surface may also result in bush fires (domino effect).

The location of the metering and pressure reduction station on the northern boundary in Alternative 1 (CCGT), creates the worst case by virtue of its closer approach to the site boundary. Figure 20 shows the extent of the 4,10 and 35 kW/m^2 thermal radiation from jet fires under strong wind conditions. The thin lines indicate the orientation of the release, while the thicker lines indicate the *effect zone* with a flame from all orientations.

The 35 kW/m^2 isopleth indicative of a 100% fatality also extends beyond the site boundary thermal-radiation isopleth which is a concern.

LEGEND **SCENARIOS (1% Fatality)**

Red	Plant Feed from the CPF (pipeline rupture)
Yellow	Plant Feed to turbines (pipeline rupture)
Blue	Gas Turbine Feed (pipeline rupture)

Figure 18:10 kW/m^2 Thermal radiation isopleths for jet fire release scenarios (Alternative 1)

LEGEND **SCENARIOS (1% Fatality)**

Red	Plant Feed from the CPF (pipeline rupture)
Yellow	Plant Feed to turbines (pipeline rupture)
Blue	Gas Engine Feed (pipeline rupture)

Figure 19: 10 kW/m^2 Thermal radiation isopleths for jet fire release scenarios (Alternative 2)

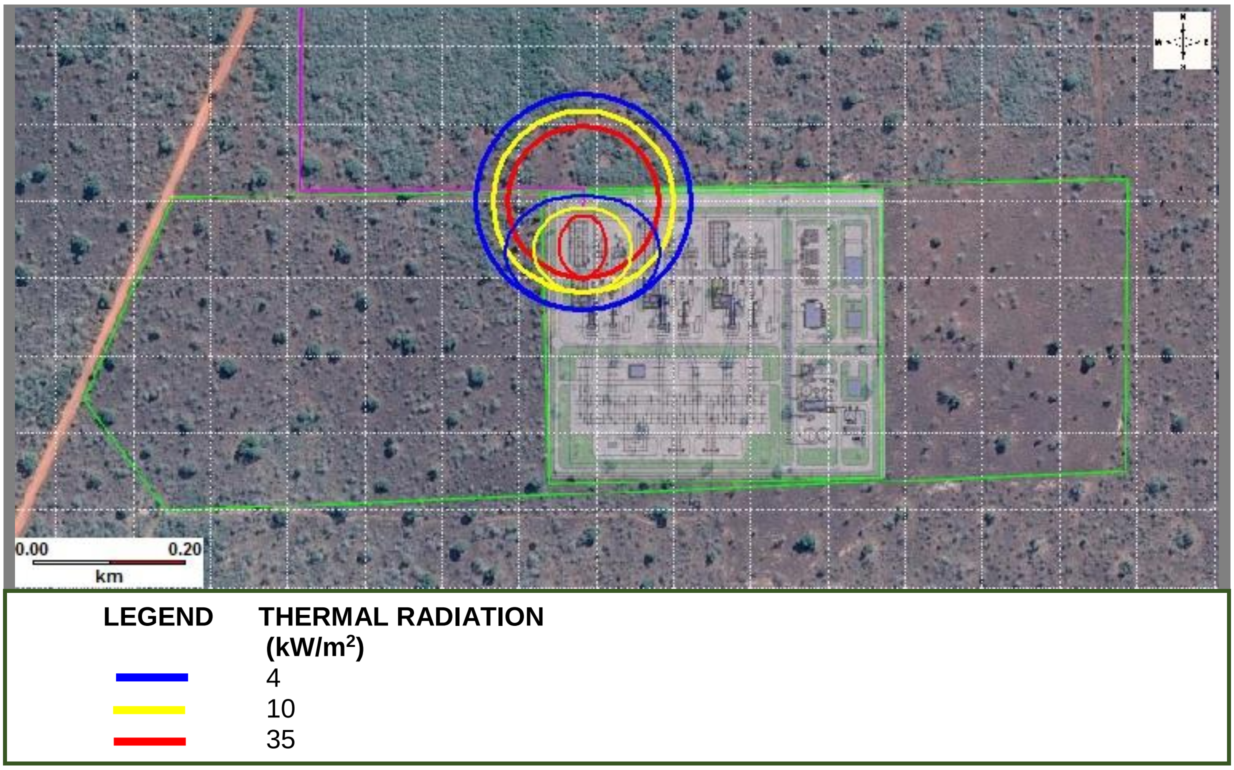


Figure 20: Isopleths representing worst case thermal radiation from a jet fire (Alternative 1)

8.2.2 Flash Fires

A loss of containment of a flammable component may mix with air, forming a flammable mixture. The flammable cloud would be defined by the lower flammable limit (LFL) and the upper flammable limit (UFL). The extent of the flammable cloud would depend on the quantity of the released and mixed component, physical properties of the released component, wind speed and weather stability.

An ignition within a flammable cloud can result in an explosion if the front is propagated by pressure. If the front is propagated by heat, then the fire moves across the flammable cloud at the flame velocity and is called a flash fire. Flash fires are characterised by low overpressure, and injuries are caused by thermal radiation. The effects of overpressure due to an exploding cloud are covered in the subsection dealing with vapour cloud explosions (VCEs).

A flash fire would extend to the lower flammable limit; however, due to the formation of pockets, it could extend beyond this limit to the point defined as the ½ LFL. It is assumed that people within the flash fire would experience lethal injuries while people outside of the flash fire would remain unharmed. The ½ LFL is used for emergency planning to evacuate people to a safe distance in the event of a release.

8.2.2.1 CPF to CTT Underground Gas Pipeline

No significant flash fire envelopes/flash fires were generated at the receiver height of 1 m above the ground for the scenarios simulated for the jet fires. This prompted an investigation of the possible reasons.

Vertical releases of buoyant gases were found to form vapour clouds that have elevated centre lines well above ground level, the height being dependant on the mixing height used for the simulations. These clouds did not extend to the ground but extended over quite a large area. Worst case conditions (stable conditions 1.5 F, 50 m mixing height) have used to illustrate this concept as shown in the cloud side view contained in Figure 21. The cloud does not contact ignition sources which are taken at a 1 m receiver height and no flash fire or vapour cloud explosions would be generated during the simulations.

The presence of ignition sources at elevated heights such as flares or tall buildings in close proximity to the pipeline could generate flash fires and vapour cloud explosions. Further investigation would be required to ensure that the correct safety distances/servitudes are implemented to maintain the integrity of the pipeline.

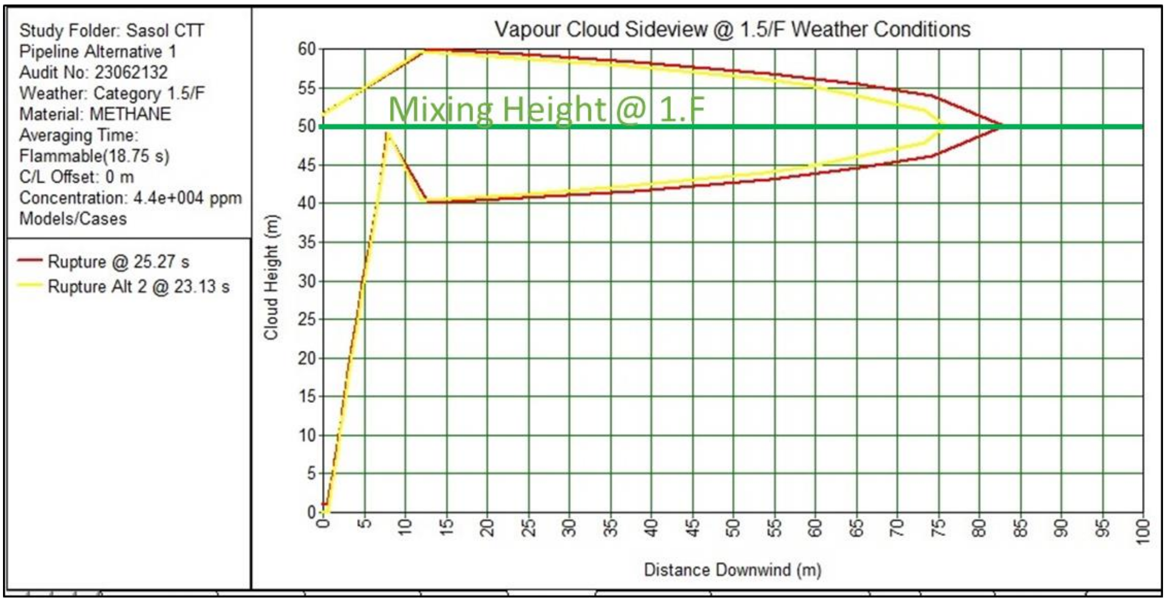


Figure 21: Sideview of the vapour cloud at the LFL @ 1.5 F weather conditions (Alternative 2)

8.2.2.2 CTT Gas Power Plant

Flash-fire scenarios were developed based on the scenarios developed for the jet fires for worst case high wind speed conditions (9 m-. s). Flash fire envelopes for all wind directions for both the LFL (lower flammable limit) and the ½ LFL concentration levels are presented for the two technology options Figure 22 (CCGT) and **Figure 23** (OCGE). The effects demonstrated by the two technology options are fairly similar. Potential offsite impacts for the LFL (flammable cloud) at the gas metering and reduction station require further investigation in the risk assessment.

Unprotected people within the flammable range would experience lethal injuries. It is recommended that under emergency conditions people should be evacuated to the ½ LFL distance downwind of the release, as given as shown in the two diagrams.

While fatalities could occur beyond the site boundaries, the surrounding area is undeveloped reducing the probability of fatalities.

The release with the largest off-site impacts is shown in Figure 24, indicated by the LFL at 1.5 m/s wind speed, which corresponds to the worst-case of the largest releases, i.e. catastrophic rupture of the incoming natural gas line at the metering and pressure reduction station. In this instance, the thin lines represent the plume from a northerly wind direction which is relatively small in area, while the thicker lines represent the wind from all directions. The northerly wind direction used does not indicate the predominant wind but is used for illustrative purposes only.

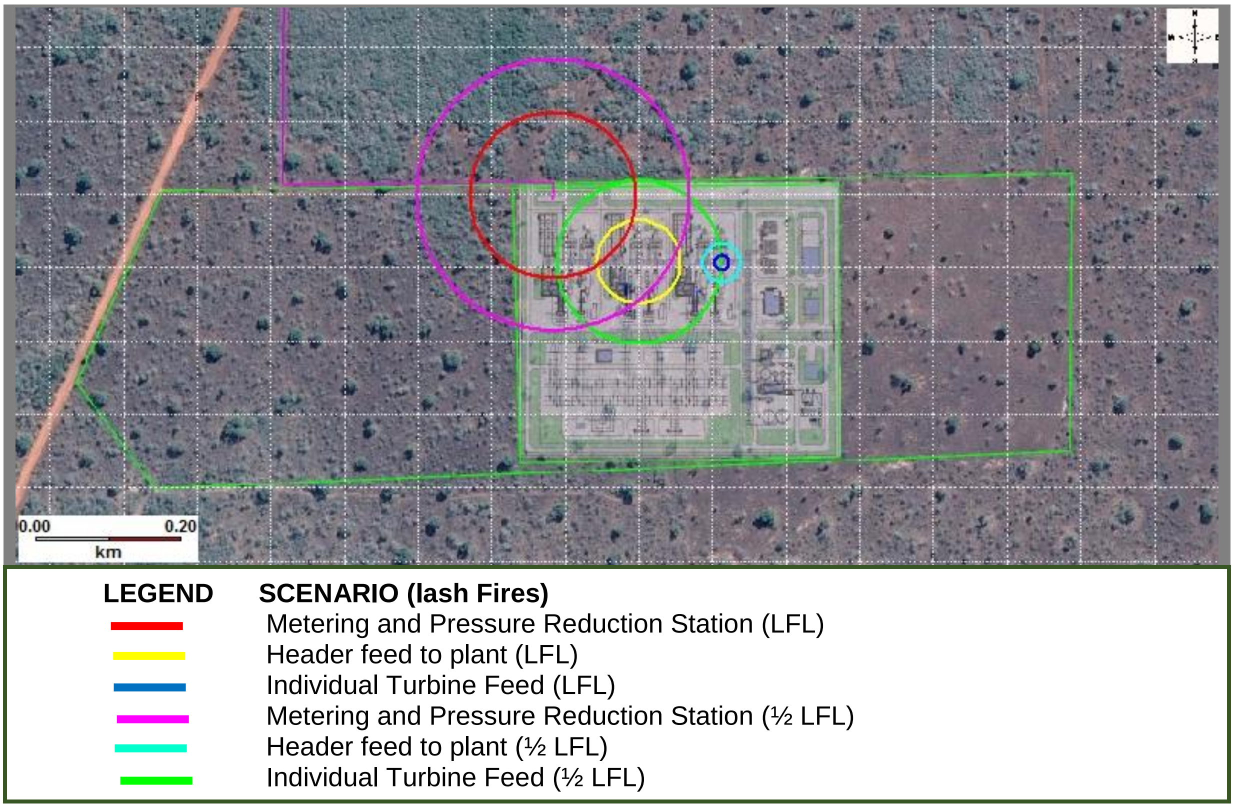


Figure 22: Flash fire limits due to a release of natural gas (Alternative 1, CCGT)

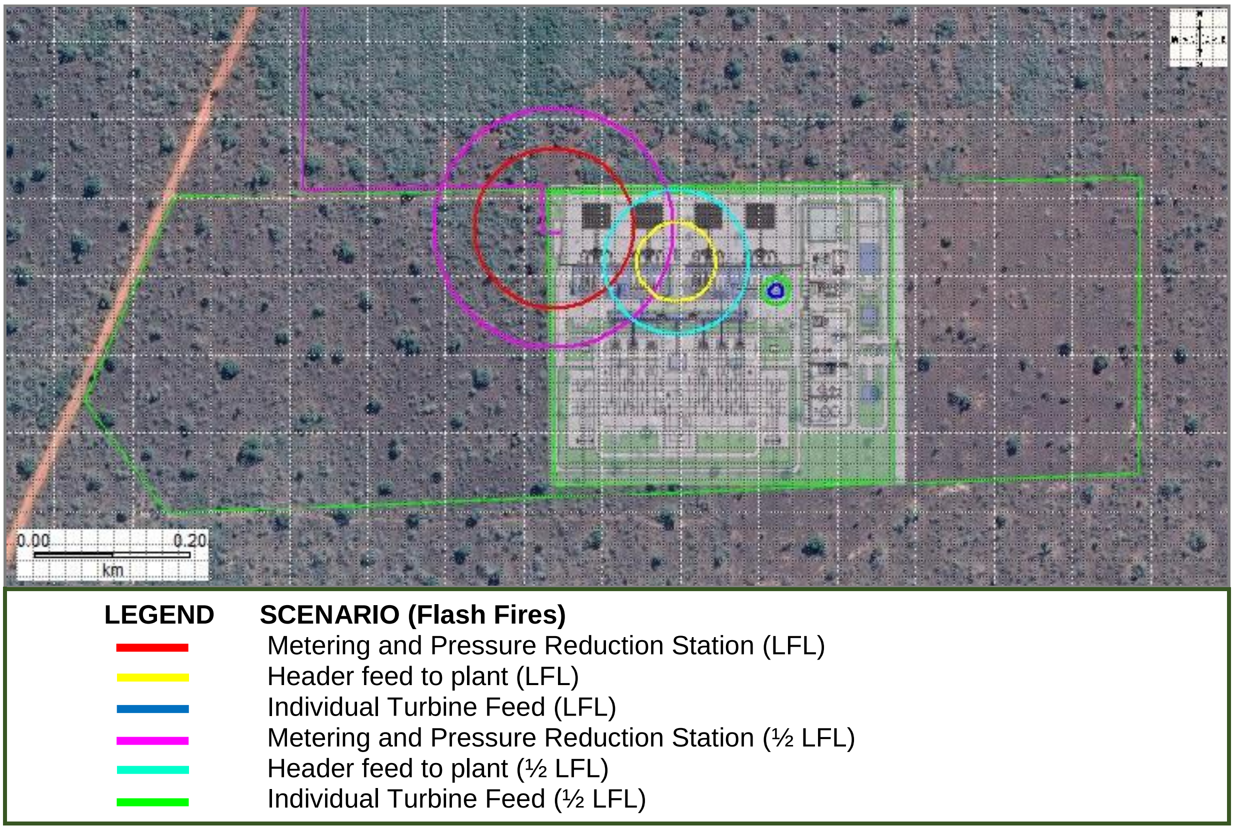


Figure 23: Flash fire limits due to a release of natural gas (Alternative 2, CCGT)

LEGEND **SCENARIO (Flash Fires)**

- (red) Metering and Pressure Reduction Station (LFL)
- (yellow) Metering and Pressure Reduction Station (½ LFL))

Figure 24: Worst case flash fire indicating the consequence from a northerly wind direction

8.3 Explosions

The concentration of a flammable component would decrease from the point of release to below the lower explosive limits (LEL), at which concentration the component can no longer ignite. The sudden detonation of an explosive mass would cause overpressures that could result in injury or damage to property.

Such an explosion may give rise to any of the following effects:

i) Blast damage;

ii) Thermal damage;

iii) Missile damage;

iv) Ground tremors;

v) Crater formation;

vi) Personal injury.

Obviously, the nature of these effects depends on the pressure waves and the proximity to the actual explosion. Of concern in this investigation are the ‘far distance effects’, such as limited structural damage and the breakage of windows, rather than crater formations.

Table 17: and Figure 26 give a more detailed summary of the damage produced by an explosion due to various overpressures.

CPR 18E (Purple Book; 1999) suggests the following overpressures be determined:

a) 0.03 bar overpressure, corresponding to the critical overpressure causing windows to break;

b) 0.1 bar overpressure, corresponding to 10% of the houses being severely damaged and a probability of death indoors equal to 0.025:

- No lethal effects are expected below 0.1 bar overpressure on unprotected people in the open.

c) 0.3 bar overpressure, corresponding to structures being severely damaged and 100% fatality for unprotected people in the open;

d) 0.7 bar overpressure, corresponding to an almost entire destruction of buildings.

Table 17: Summary of consequences of blast overpressure (Clancey 1972)

Pressure (Gauge)		Damage
Psi	**kPa**	
0.02	0.138	Annoying noise (137 dB), if of low frequency (10 – 15 Hz)
0.03	0.207	Occasional breaking of large glass windows already under strain
0.04	0.276	Loud noise (143 dB); sonic boom glass failure
0.1	0.69	Breakage of small under strain windows
0.15	1.035	Typical pressure for glass failure
0.3	2.07	'Safe distance' (probability 0.95; no serious damage beyond this value); missile limit; some damage to house ceilings; 10% window glass broken
0.4	2.76	Limited minor structural damage
0.5 – 1.0	3.45 – 6.9	Large and small windows usually shattered; occasional damage to window frames
0.7	4.83	Minor damage to house structures
1.0	6.9	Partial demolition of houses made uninhabitable
1.0 – 2.0	6.9 – 13.8	Corrugated asbestos shattered; corrugated steel or aluminium panels, fastenings fail, followed by buckling; wood panels (standard housing) fastenings fail, panels blown in
1.3	8.97	Steel frame of clad building slightly distorted
2.0	13.8	Partial collapse of walls and roofs of houses
2.0 – 3.0	13.8 – 20.7	Concrete or cinderblock walls (not reinforced) shattered
2.3	15.87	Lower limit of serious structural damage
2.5	17.25	50% destruction of brickwork of house

Pressure (Gauge)		Damage
Psi	**kPa**	
3.0	20.7	Heavy machines (1.4 t) in industrial building suffered little damage; steel frame building distorted and pulled away from foundations
3.0 – 4.0	20.7 – 27.6	Frameless, self-framing steel panel building demolished
4.0	27.6	Cladding of light industrial buildings demolished
5.0	34.5	Wooden utilities poles (telegraph, etc.) snapped; tall hydraulic press (18 t) in building slightly damaged
5.0 – 7.0	34.5 – 48.3	Nearly complete destruction of houses
7.0	48.3	Loaded train wagons overturned
7.0 – 8.0	48.3 – 55.2	Brick panels (20 – 30 cm) not reinforced fail by shearing or flexure
9.0	62.1	Loaded train boxcars completely demolished
10.0	69.0	Probable total destruction buildings; heavy (3 t) machine tools moved and badly damaged; very heavy (12 000 lb. / 5443 kg) machine tools survived
300	2070	Limit of crater lip

Table 18: Damage caused by overpressure effects of an explosion (Stephens 1970)

Equipment	Overpressure (psi)																									
	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	12	14	16	18	20		
Control house steel roof	A	C	V				N																			A	Windows and gauges break
Control house concrete roof	A	E	P	D			N																			B	Louvers fall at 0.3–0.5 psi
Cooling tower	B			F			O																			C	Switchgear is damaged from roof collapse
Tank: cone roof		D				K							U													D	Roof collapses
Instrument cubicle			A			LM						T														E	Instruments are damaged
Fire heater				G	I					T																F	Inner parts are damaged
Reactor: chemical				A				I				P						T								G	Bracket cracks
Filter				H					F									V			T					H	Debris-missile damage occurs
Regenerator						I				IP					T											I	Unit moves and pipes break
Tank: floating roof						K							U												D	J	Bracing fails
Reactor: cracking							I							I							T					K	Unit uplifts (half filled)
Pipe supports							P					SO														L	Power lines are severed
Utilities: gas meter									Q																	M	Controls are damaged
Utilities: electric transformer									H					I						T						N	Block wall fails
Electric motor										H								I							V	O	Frame collapses
Blower										Q										T						P	Frame deforms
Fractionation column											R			T												Q	Case is damaged
Pressure vessel horizontal												PI						T								R	Frame cracks
Utilities: gas regulator												I								M Q						S	Piping breaks
Extraction column													I							V	T					T	Unit overturns or is destroyed
Steam turbine															I						M	S			V	U	Unit uplifts (0.9 filled)
Heat exchanger															I			T								V	Unit moves on foundations
Tank sphere																I						I	T				
Pressure vessel vertical																					I	T					
Pump																					I		Y				

8.3.1 Vapour Cloud Explosions (VCEs)

The release natural gas into the atmosphere could result in formation of a flash fire, as described in the subsection on flash fires, or a vapour cloud explosion (VCE). In the case of a VCE, an ignited vapour cloud between the higher explosive limits (HEL) and the lower explosive limit (LEL) could form a fireball with overpressures that could result in injury or damage to property.

8.3.1.1 CPF to CTT Underground Gas Pipeline

As indicated in the section on flash fires no vapour cloud explosion was anticipated at the receiver/ ignition height of 1 m, in the simulation of any of the natural gas pipeline scenarios.

8.3.1.2 CTT Gas Power Plant

A loss of containment of natural gas with an ignition source could form a flash fire as described in Section 7.2 or a vapour cloud explosion. The 0.1 bar blast overpressure isopleths have been selected for analysis as they are considered to represent the 1% fatality.

Figure 25 and Figure 26 indicate the blast overpressures of 0.1 bar from the release of flammable vapours from loss of containment scenarios under worst meteorological conditions. In each scenario, the vapours drifted to an ignition point before detonating. This is referred to as a *late explosion*. The lines do not indicate the effects of a single explosion but the effect area from all wind directions. The thin lines indicate the overpressure from vapours drifting from a northerly wind, while the thicker lines show the effect zone from drifting clouds from all wind directions. The northerly wind direction used does not indicate the predominant wind but is used as illustrative purposes only.

The 1% fatality does extend over the northern site boundary based on a release at the metering and pressure reduction station. Further analysis would be required. While fatalities could occur beyond the site boundaries, the surrounding area is largely undeveloped scrubby bush reducing the probability of fatalities.

LEGEND **SCENARIO**

- (red) Metering and Pressure Reduction Station
- (yellow) Header feed to plant
- (blue) Individual Turbine Feed

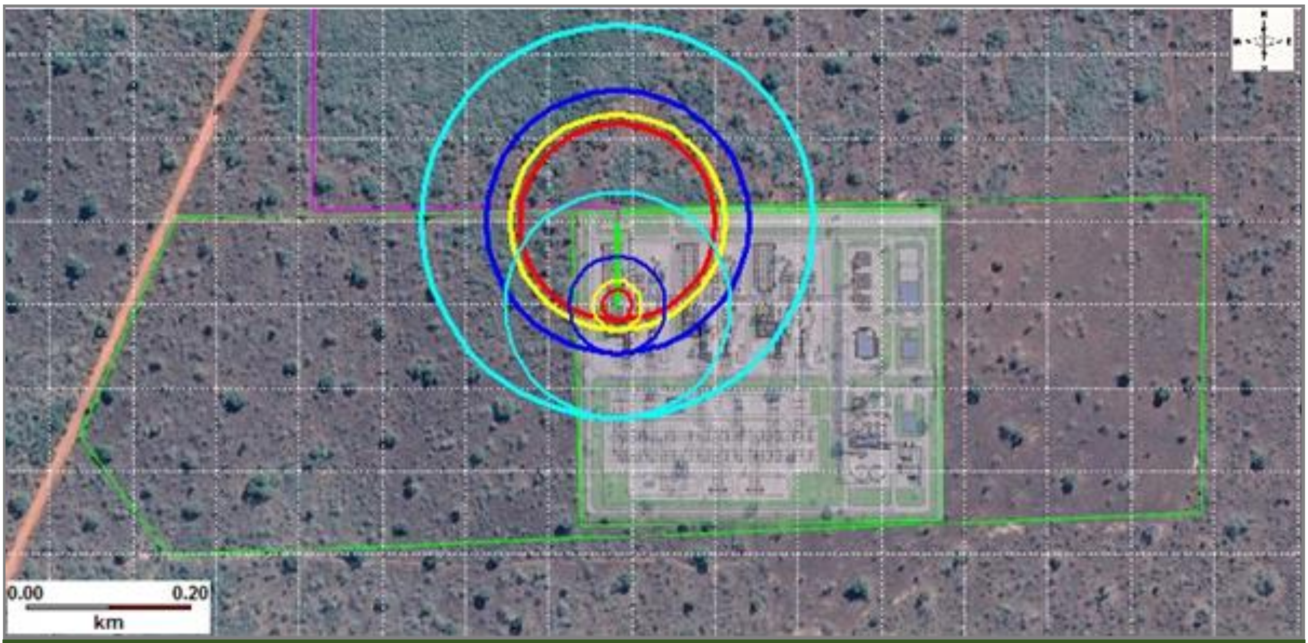
Figure 25: 0.1 bar overpressures from VCEs due to flammable natural gas releases (Alternative 1, CCGT)

LEGEND	SCENARIO
Red	Metering and Pressure Reduction Station
Yellow	Header feed to plant
Blue	Individual Engine Feed

Figure 26: 0.1 bar overpressures from VCEs from flammable natural gas release (Alternative 2, OCGE)

A graphical representation of the worst-case blast overpressures is given in Figure 27 . In this case, it is the for a line rupture at the receiving and pressure reduction station in Alternative 1 (CGT). As with the previous figures, the thin lines indicate the overpressure from vapours drifting from a northerly wind, while the thicker lines show the effect zone from drifting clouds from all wind directions. The northerly wind direction used does not indicate the predominant wind but is used as illustrative purposes only.

The 0.7 bar overpressure would result in almost entire destruction of buildings and 100% fatality for people in the open, while the 0.3 bar would cause severe damage to buildings and fatalities. The 0.1 bar overpressure, corresponding to 10% of the houses severely damaged and a probability of death indoors equal to 0.025. No lethal effects are expected below 0.1 bar overpressure for people in the open. A summary of these overpressures with various scenarios is given in Figure 27.



LEGEND	SCENARIO
(red)	0.7 bar
(yellow)	0.3
(blue)	0.1 bar
(cyan)	0.03 bar

Figure 27: Worst Case overpressures from VCEs due to natural gas (Alternative 1)

9.0 RISK

9.1 Background

It is important to understand the difference between hazard and risk.

A hazard is anything that has the potential to cause damage to life, property and the environment. Furthermore, it has constant parameters (like those of petrol, chlorine, ammonia, etc.) that pose the same hazard wherever present.

On the other hand, risk is the probability that a hazard will actually cause damage and goes along with how severe that damage will be (consequence). Risk is therefore the probability that a hazard will manifest itself. For instance, the risks of a chemical accident or spill depends upon the amount present, the process the chemical is used in, the design and safety features of its container, the exposure, the prevailing environmental and weather conditions and so on.

Risk analysis consists of a judgement of probability based on local atmospheric conditions, generic failure rates and severity of consequences, based on the best available technological information.

Risks form an inherent part of modern life. Some risks are readily accepted on a day-to-day basis, while certain hazards attract headlines even when the risk is much smaller, particularly in the field of environmental protection and health. For instance, the risk of one-in-ten-thousand chance of death per year associated with driving a car is acceptable to most people, whereas the much lower risks associated with nuclear facilities (one-in-ten-million chance of death per year) are deemed unacceptable.

A report by the British Parliamentary Office of Science and Technology (POST), entitled ‘Safety in Numbers? Risk Assessment and Environmental Protection’, explains how public perception of risk is influenced by a number of factors in addition to the actual size of the risk.

These factors were summarised as follows in Table 19.

Table 19: Influence of public perception of risk on acceptance of that risk, based on the POST report

Control	People are more willing to accept risks they impose upon themselves or they consider to be 'natural' than to have risks imposed upon them
Dread and Scale of Impact	Fear is greatest where the consequences of a risk are likely to be catastrophic rather than spread over time.
Familiarity	People appear more willing to accept risks that are familiar rather than new risks.
Timing	Risks seem to be more acceptable if the consequences are immediate or short term, rather than if they are delayed (especially if they might affect future generations).
Social Amplification and Attenuation	Concern can be increased because of media coverage, graphic depiction of events or reduced by economic hardship.
Trust	A key factor is how far the public trusts regulators, policy makers or industry; if these bodies are open and accountable (being honest as well as admitting mistakes and limitations and taking account of differing views without disregarding them as emotive or irrational), then the public is more likely consider them credible.

A risk assessment should be seen as an important component of ongoing preventative action, aimed at minimising or hopefully avoiding accidents. Reassessments of risks should therefore follow at regular intervals and after any changes that could alter the nature of the hazard, so contributing to an overall prevention programme and emergency response plan of the facility. Risks should be ranked with decreasing severity and the top risks reduced to acceptable levels.

Procedures for predictive hazard evaluation have been developed for the analysis of processes when evaluating very low probability accidents with very high consequences (for which there is little or no experience) as well as more likely releases with fewer consequences (for which there may be more information available). These addresses both the probability of an accident as well as the magnitude and nature of undesirable consequences of that accident. Risk is usually defined as some simple function of both the probability and consequence.

9.2 Predicted Risk

Physical and consequence modelling addresses the impact of a release of a hazardous component without considering the probability of occurrence. This merely illustrates the significance and the extent of the impact in the event of a release. Modelling should also analyse cascading or knock-on effects due to incidents in the facility and the surrounding industries and suburbs.

During a risk analysis, the likelihood of various incidents is assessed, the consequences calculated and finally the risk for the facility is determined.

9.2.1 Generic Equipment Failure Scenarios

In order to characterise various failure events and assign a failure frequency, fault trees were constructed starting with a final event and working from the top down to define all initiating events and frequencies. Unless otherwise stated, analysis was completed using published failure rate data (RIVM 2009). Equipment failures can occur in tanks, pipelines and other items handling hazardous chemical components. These failures may result in:

- Release of combustible, flammable and explosive components with fires or explosions upon ignition;
- Release of toxic or asphyxiant components.

9.3 Risk Calculations

9.3.1 Maximum Individual Risk Parameter

Standard individual risk parameters include: average individual risk; weighted individual risk; maximum individual risk; and, the fatal accident rate. The lattermost parameter is more applicable to occupational exposures.

Only the maximum individual risk (MIR) parameter will be used in this assessment. For this parameter frequency of fatality is calculated for an individual who is presumed to be present at a specified location. This parameter (defined as the consequence of an event multiplied by the likelihood of the event) is not dependent on knowledge of populations at risk. So, it is an easier parameter to use in the predictive mode than average individual risk or weighted individual risk. The unit of measure is the risk of fatality per person per year.

9.3.2 Acceptable Risks

The next step, after having characterised a risk and obtained a risk level, is to recommend whether the outcome is acceptable.

In contrast to the employees at a facility, who may be assumed to be healthy, the adopted exposure assessment applies to an average population group that also includes sensitive subpopulations. Sensitive subpopulation groups are those people that for reasons of age or medical condition have a greater than normal response to contaminants. Health guidelines and standards used to establish risk normally incorporate safety factors that address this group.

Among the most difficult tasks of risk characterisation is the definition of acceptable risk. In an attempt to account for risks in a manner similar to those used in everyday life, the UK Health and Safety Executive (HSE) developed the risk ALARP triangle. Applying the triangle involves deciding:

i) Whether a risk is so high that something must be done about it;

ii) Whether the risk is or has been made so small that no further precautions are necessary;

iii) If a risk falls between these two states so that it has been reduced to levels as low as reasonably practicable (ALARP).

This is illustrated in Figure 28.

ALARP stands for ‘as low as reasonably practicable’. As used in the UK, it is the region between that which is intolerable, at 1 x 10^{-4} per year, and that which is broadly acceptable, at 1 x 10^{-6} per year. A further lower level of risk, at 3 x 10^{-7} per year, is applied to either vulnerable or very large populations for land-use planning.

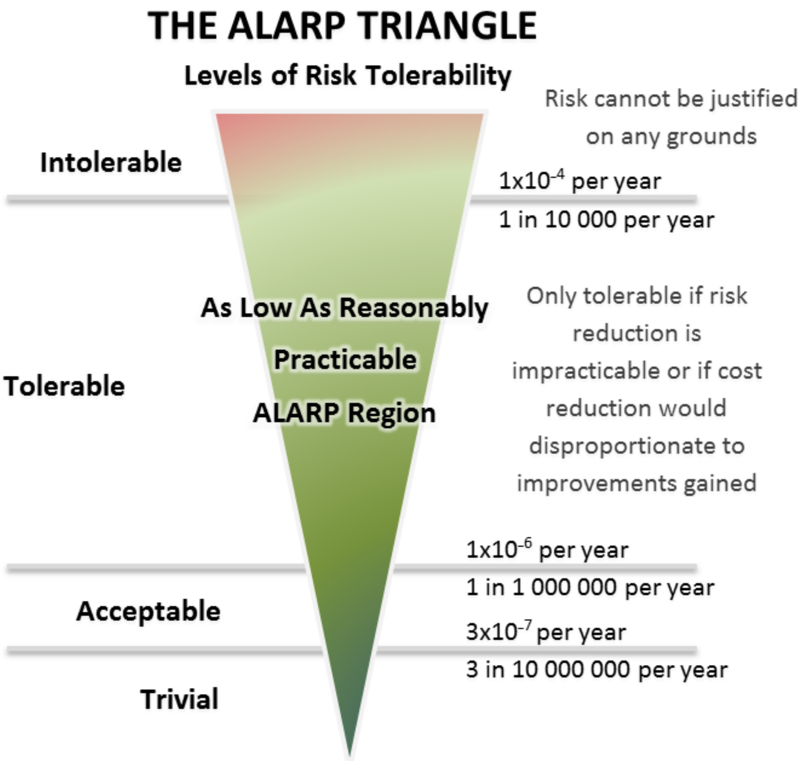


Figure 28: **UK HSE decision-making framework**

It should be emphasised that the risks considered acceptable to workers are different to those considered acceptable to the public. This is due to the fact that workers have personal protection equipment (PPE), are aware of the hazards, are sufficiently mobile to evade or escape the hazards and receive training in preventing injuries.

The HSE (UK) gives more detail on the word practicable in the following statement:

1) "*In essence, making sure a risk has been reduced to ALARP is about weighing the risk against the sacrifice needed to further reduce it. The decision is weighted in favour of health and safety because the presumption is that the duty-holder should implement the risk reduction measure. To avoid having to make this sacrifice, the duty-holder must be able to show that it would be grossly disproportionate to the benefits of risk reduction that would be achieved. Thus, the process is not one of balancing the costs and benefits of measures but, rather, of adopting measures except where they are ruled out because they involve grossly disproportionate sacrifices. Extreme examples might be:*

   i) To spend £1 m to prevent five staff members suffering bruised knees is obviously grossly disproportionate; but,

   ii) To spend £1m to prevent a major explosion capable of killing 150 people is obviously proportionate.

2) *Proving ALARP means that if the risks are lower than 1 x 10^{-4} fatalities per person per year, it can be demonstrated that there would be no more benefit from further mitigation, sometimes using cost benefit analysis.*"

9.3.3 Land Planning

There are no legislative land-planning guidelines in many parts of the world. Further to this, land-planning guidelines vary from one country to another, and thus it is not easy to benchmark the results of this study to international criteria. In this instance, RISCOM would only advise on applicable land planning and would require governmental authorities to make final decisions.

Land zoning applied in this study follows the HSE (UK) approach of defining the area affected into three zones, consistent with the ALARP approach (HSE 2011).

The three zones are defined as follows:

i) the inner zone (IZ) enclosed by the 1 x 10^{-5} fatalities per person per year isopleth;

ii) the middle zone (MZ) enclosed by the 1 x 10^{-5} and 1 x 10^{-6} fatalities per person per year isopleths;

iii) the outer zone (OZ) is enclosed by the 1 x 10^{-6} and 3 x 10^{-7} fatalities per person per year isopleths.

The risks decrease from the inner zone to the outer zone as shown in Figure 29 and Figure 30.

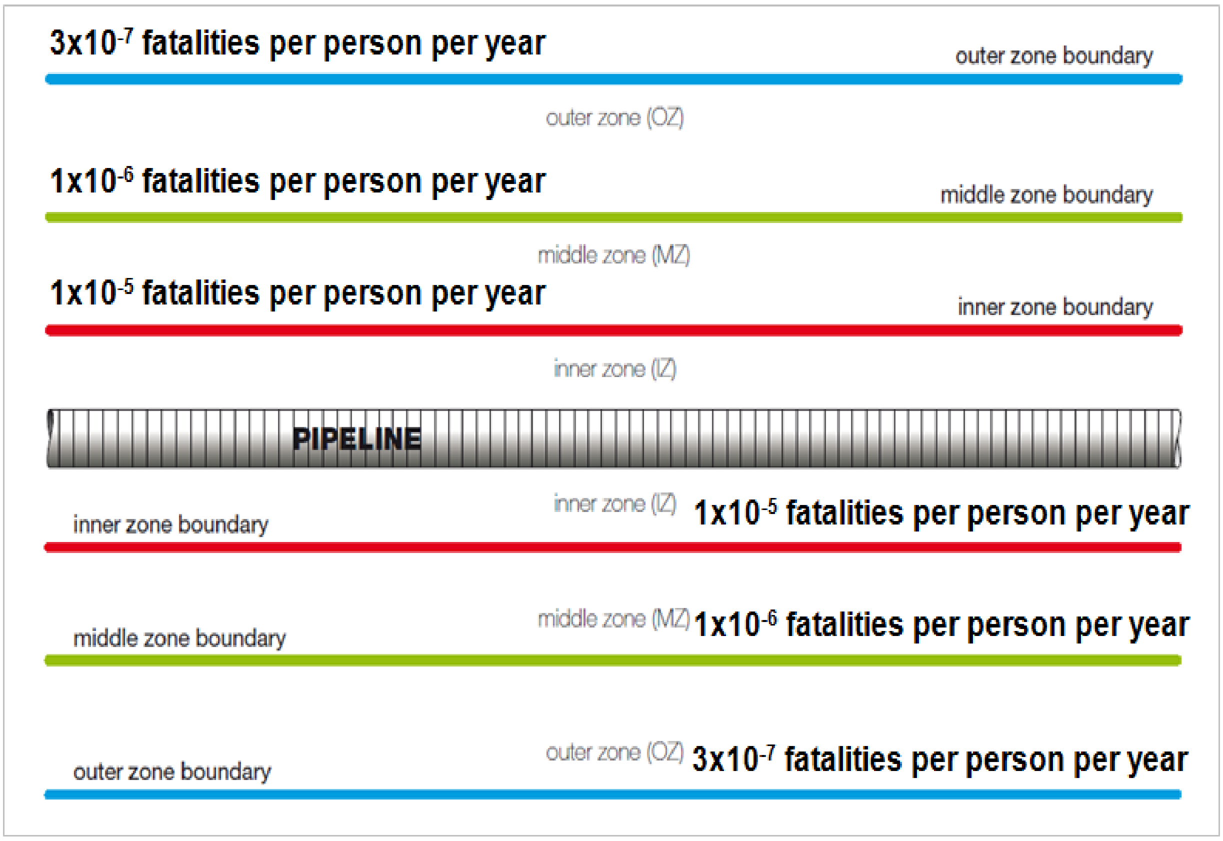


Figure 29: Town-planning zones for pipelines

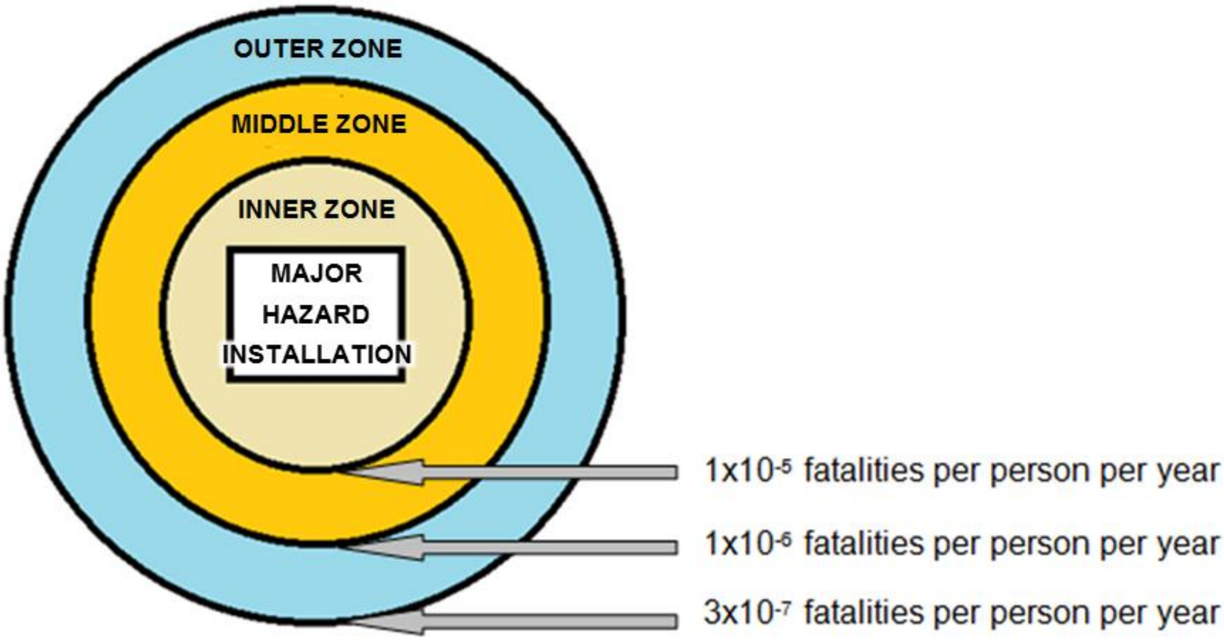


***Figure 30*:Town-planning zones**

Once the zones are calculated, the HSE (UK) methodology then determines whether a development in a zone should be categorised as ‘advised against’ (AA) or as ‘don’t advise against’ (DAA), depending on the sensitivity of the development, as indicated in Table 20.There are no land-planning restrictions beyond the outer zone.

Table 20: Land-use decision matrix

Level of Sensitivity	Development in Inner Zone	Development in Middle Zone	Development in Outer Zone
1	DAA	DAA	DAA
2	AA	DAA	DAA
3	AA	AA	DAA
4	AA	AA	AA

The sensitivity levels are based on a clear rationale: progressively more severe restrictions are to be imposed as the sensitivity of the proposed development increases. There are four sensitivity levels, with the sensitivity for housing defined as follows:

i) Level 1 is based on workers who have been advised of the hazards and are trained accordingly;

ii) Level 2 is based on the general public at home and involved in normal activities;

iii) Level 3 is based on the vulnerability of certain members of the public (e.g. children, those with mobility difficulties or those unable to recognise physical danger);

iv) Level 4 is based on large examples of Level 2 and of Level 3.

Detailed planning advice for developments near hazardous installations (PADHI) tables (HSE(2011). These tables illustrate how the HSE land-use decision matrix, generated using the three zones and the four sensitivity levels, is applied to a variety of development types.

9.4 Risk Scenarios

9.4.1 Accidental Fires and Explosions Involving Natural Gas

Relatively large quantities of flammable natural gas are to be delivered from the CPF to the CTT power plant and combusted to produce electricity at the CTT site. Two technology options are under consideration namely CCGT and OCGE, each of which will be considered from a risk to the public perspective. Based on the magnitude and similarity of the type of consequences developed in the previous section any difference is anticipated to lie in the specific layouts adopted for each alternative.

Fires (jet and flash) and explosions (vapour cloud) may result with accidental release and ignition of this natural gas, as a result of incidents that occur in either of the two options. The combined site risks for each option have been calculated, based on generic equipment failure rates/ignition probabilities obtained from the Bevi manual (Appendix D) and the consequences developed in Section 7 of this report.

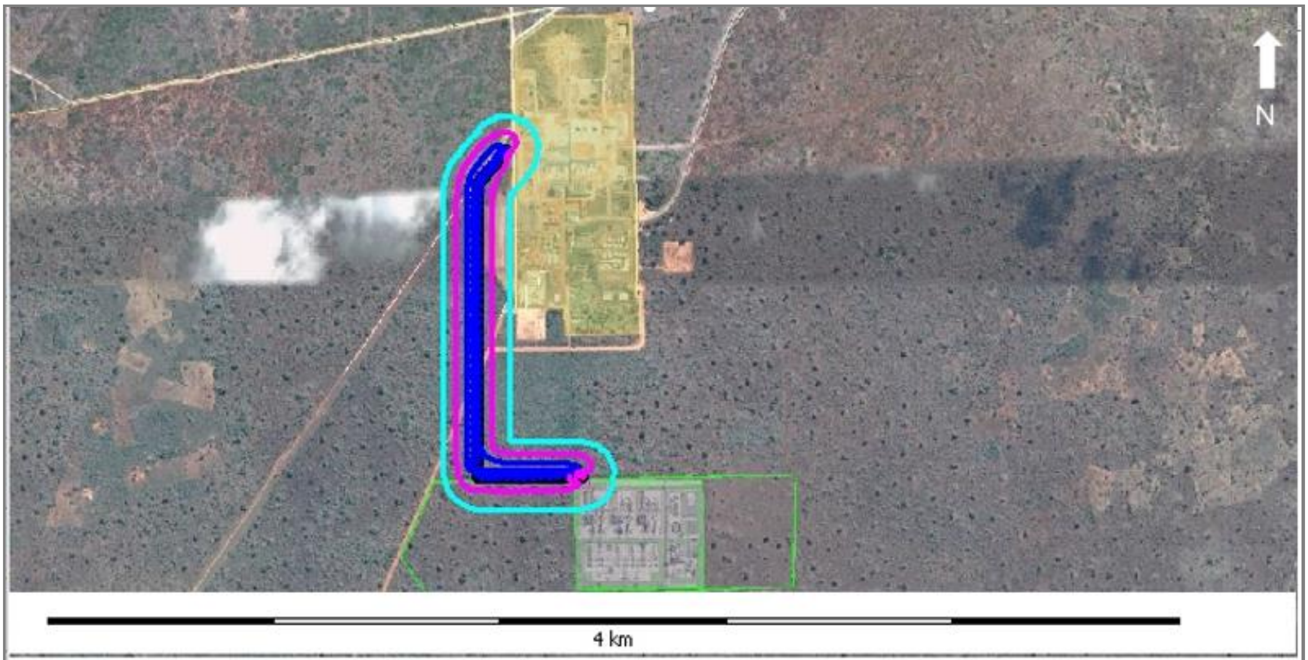
The risk isopleths are prepared from those scenarios identified as requiring investigation and are presented as follows:

- A risk isopleth diagram for the underground pipeline from the CPF for each technology alternative;
- A risk isopleth diagram showing the interaction of the CPF pipeline and each of the power generation technology options.

It can be demonstrated that the risk profiles of each of the technology have significant similarities to each other namely:

- The combined risks for each of the two options lie in the low ALARP range (1 x 10^{-6} fatalities per person per year to 1 x 10^{-4} fatalities per person per year);
- The 1 x 10^{-6} fatalities per person per year isopleths extends a small distance beyond the northern boundary in each instance, but typically less than 80 m and do not affect the CPF which lies to the north of the CTT power plant. The isopleth for the pipeline routing does not impact the CPF.
- This is an area of natural vegetation provided for separation between the CPF and the CTT power plant and would not be an issue provided this land remains zoned for industrial use;
- The proposed underground pipeline does cross some the existing pipelines to the well pads and this would a consideration from a construction perspective;
- The 3 x 10^{-7} fatalities per person per year isopleth for the gas power plant and natural gas pipeline indicates boundary that would be suitable for vulnerable populations, such as hospitals, retirement homes, nursery schools, prisons, large gatherings in the open, and so forth. This is unlikely to have little impact provided the future land use is zoned for industrial;
- The 3 x 10^{-9} considered as the threshold for environmental risks/risks to the public in the Bevi manual would not impact the surrounding communities or neighbouring businesses for either technology option, as they are currently proposed.
- The small differences in the risk associated with the two options are largely attributable to differences in layout e.g. The location of the metering station and the routing the natural gas pipeline and some of the pipes within the power plants.

9.4.1.1 Underground Pipeline from the CPF



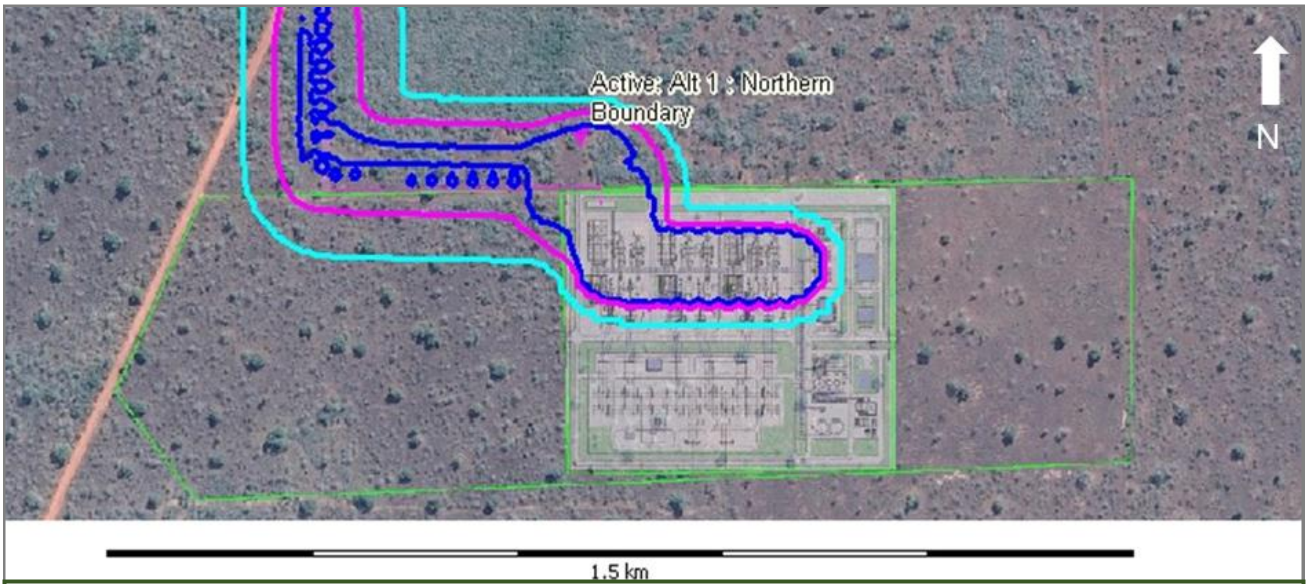
LEGEND **RISK**
(fatalities per person per year)
$1x10^{-4}$ (not reached)
$1x10^{-5}$ (not reached)
$1x10^{-6}$
$3x10^{-7}$
$1x10^{-9}$ (Bevi risk screening criteria)

Figure 31: Lethal probability isolines associated with the CCGT natural gas fuel line

LEGEND **RISK**
(fatalities per person per year)
$1x10^{-4}$ (not reached)
$1x10^{-5}$ (not reached)
$1x10^{-6}$
$3x10^{-7}$
$1x10^{-9}$ (Bevi risk screening criteria)

Figure 32: Lethal probability isolines associated with the OCGE natural gas fuel line

9.4.1.2 Power Generation Plants

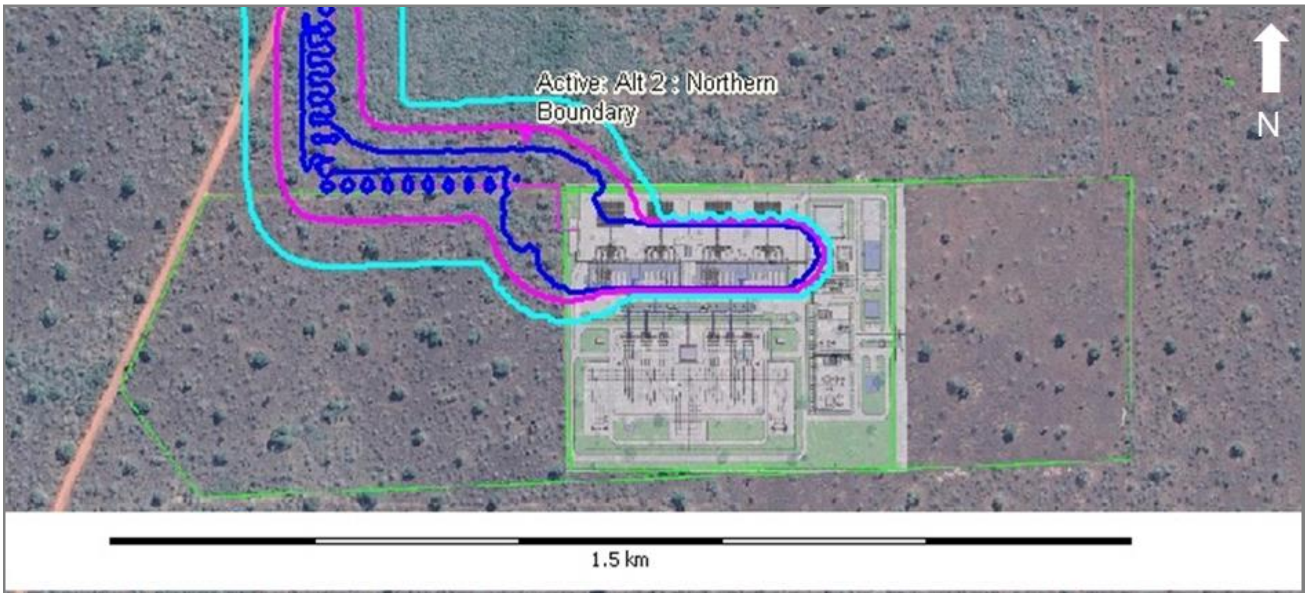


LEGEND **RISK**

(fatalities per person per year)

- $1x10^{-4}$ (not reached)
- $1x10^{-5}$ (not reached)
- $1x10^{-6}$
- $3x10^{-7}$
- $1x10^{-9}$ (Bevi risk screening criteria)

Figure 33: Lethal probability isolines associated with the CCGT fuel line and gas power plant



LEGEND **RISK**

(fatalities per person per year)

- $1x10^{-4}$ (not reached)
- $1x10^{-5}$ (not reached)
- $1x10^{-6}$
- $3x10^{-7}$
- $1x10^{-9}$ (Bevi risk screening criteria)

Figure 34: Lethal probability isolines associated with the OCGE fuel line and gas power plant

9.5 Societal Risk Parameter

The risk criteria discussed so far have been for individual risks. There is also a need to consider incidents in the light of their effect on many people at the same time. Public response to an incident that may harm many people is thought to be worse than the response to many incidents causing the same number of individual deaths. Compliance with an individual risk criterion is necessary but not always sufficient. Even if it were sufficient, societal risk would also have to be examined in some circumstances.

Societal risk is the risk of widespread or large-scale harm from a potential hazard. The implication is that consequence would be on such a scale as to provoke a major social or political response and may lead to public discussion about regulation in general. Societal risk therefore considers the density of the population around a Major Hazard Installation site and is the probability in any one year (F) of an event affecting at least a certain number (N) of people (also known as an FN curve).

Societal risk used in this study is based on legal requirements in the Netherlands and may differ from risk criteria and requirements in other parts of the world.

The surrounding areas are largely bush/natural vegetation, and there is little evidence to suggest that the land is inhabited. In the absence of a population density it has not been possible to generate an FN curve. On this basis, the societal risks for both alternatives would not exceed the threshold value and are not presented.

10.0 REDUCTION OF RISK

Based on the simulations performed, the areas of highest risk for both alternatives have been identified as the release of Natural Gas at the metering and pressure reduction station.

Mitigation that may be considered to reduce risks to acceptable levels is listed in following subsections.

It should be noted that suggested mitigation is for consideration only. RISCOM does not imply that the suggested mitigation should be implemented or that any suggested mitigation is the only measure to reduce risks. Furthermore, implementation of some or all of the suggested mitigation would not guarantee full compliance with the Major Hazard Installation regulations.

Implementation of any mitigation should always be done in accordance with recognised engineering practices, using applicable codes and standards.

10.1 Risk Ranking

This risk assessment considered numerous scenarios determining both consequences and a probability of release. Some scenarios have more serious consequences than others. However, the scenarios of particular interest are those with high risk frequencies extending beyond the boundary of the site.

Table 21 and Table 22 summaries the risk ranking of the largest contributors to off-site risk for certain analysis points (shown in the ranking can be used to effectively to mitigate risks by prioritisation and setting of budgets).

Table 21:Off-site risk rankings at analysis point – Alternative 1 (Alt 1 Northern Boundary)
Total Individual Risk at analysis point is: 1.51E-06/yr

Scenario	Frequency (per annum)	Risk Contribution (%)
Rupture (Jet fire) Gas Fuel Feedline from CPF	5.41E-07	35.9
Rupture (Flash Fire) Metering/Pressure Reduction Station	5.33E-07	35.4
Rupture (Jet fire) Metering/Pressure Reduction Station	4.34E-07	28.8

Table 22: Off-site risk rankings at analysis point – Alternative 2 (Alt 2 Northern Boundary)
Total Individual Risk at analysis point: 6.12E-07 /yr

Scenario	Frequency (per annum)	Risk Contribution (%)
Rupture (Jet fire) Gas Fuel Feedline from CPF	6.12E-07	100

The small differences in the risk associated with the two options are largely attributable to differences in layout, as illustrated by the increased combined risk in the case of Alternative 1, due to the closer proximity of the metering and pressure reduction station to the plant boundary.

10.2 Mitigation

10.2.1 Codes and Standards

Ensuring that guidelines or equivalent international recognised codes of good design and practice are incorporated into the final designs can significantly reduce the incidence of both on and off-site safety impacts. This should include those guidelines that are specific to the type of plant e.g. the specific standards that deal with the hazards pertaining to the installation of gas turbines on site (ISO/CD 21789 (ISO (2009), PM84 (HSE (2003), etc.).

10.2.2 Process Hazard Analysis (PHA)

A structured process hazard analysis (HAZOP, FMEA, etc.) should be completed for the proposed facility prior to construction to ensure that omissions in the process design are eliminated, operational hazards have been identified and effective mitigation has been put in place.

10.2.3 Land Planning

A partial protection zone (PZZ) with a radius of 500m will be deployed surrounding the site. This would effectively protect the public from the hazards/risks identified in this study (plant and gas pipeline).

10.2.4 Process Pipeline Installation/Specification

The simulations were based on an underground pipe with a typical pipe specification, with no provision for a dedicated lane, additional depth of cover, etc. Mitigations that should be considered include:

- Installation in a dedicated piping lane with carefully considered servitudes;
- Increasing the piping specification to one that is appropriate for underground specification;
- Increasing the depth of pipeline soil cover.

10.2.5 Technology Selection

There may be inherent safety attributes of a particular technology that have not been considered in this report. These may need to be investigated further.

10.2.6 Noise Abatement (Confinements)

Gas power plants often face increasingly stringent noise abatement requirements, more especially in plants built in built-up areas, but even in what would appear to be more remote areas. This often is achieved by putting in place acoustic hoods that are removable for maintenance. Such requirements may be late project inclusions or even retrofits to operational plants.

Whilst these enclosures may provide the required noise abatement they create potential confinements for explosive mixtures of natural gas and air and provide little or no protection in the event of an explosion or fire. Natural gas leaks inside gas turbine enclosures or engine rooms are a significant source of on-site incidents (with potential off-site escalation), as it is not possible to fully exclude the potential for fuel leaks and sources of ignition.

Historically this was addressed by attempting to remove sources heat and ignition from these areas, subsequently it is being recognised that the chosen basis must be to ensure that explosive mixtures cannot occur within these confined spaced. This would be similar to the methodology that is followed for the mitigation of the flammable/toxic impacts of ammonia in ammonia machine rooms.

Adequate measures would need to be put in place to ensure that the explosive and fire risks of natural gas in confined spaces would be effectively mitigated.

11.0 IMPACT ASSESSMENT

11.1 Potential Impacts of the Project

The potential environmental impacts of the CTT Project on the public, associated with the handling of hazardous chemicals have been identified, based on the QRA techniques outlined in previous sections of this report.

The Quantitative Risk Assessment has not indicated any significant differentiation between the two proposed technology alternatives considered:

- Closed Circuit Gas Turbine (CCGT) technology;
- Closed Circuit Gas Turbine (CCGT) technology.

This is not unexpected from the following perspectives:

- The required flowrates of natural gas are fairly low for both options, and the differentiation provided by introducing the HRSG and Steam Turbine for energy efficiency (reduced natural gas flow for the same power generation), is insufficient to separate the two options when accessed;
- Differences in the utilisation of water treatment chemicals and other ancillary reagents are not large enough to provide any clear differentiation from a risk perspective. The current options for water treatment, involve the use of components which are not significantly hazardous to local communities, which have been excluded from the QRA. This could however be materially affected should there be a requirement for the use of toxic gases, such as ammonia or chlorine for water treatment.

11.2 Assessment Methodology and Rating Criteria

This ESIA uses the framework provided by Golder which is contained in Appendix E.

This methodology is the basis used for developing the significance rating for each of the identified project impacts. Potential impacts are assessed according to the direction, intensity (or severity), duration, extent and probability of occurrence of the impact as contained in the sections that follow.

11.3 Identified impacts

11.3.1 Construction phase impacts

Small quantities of hazardous materials such as diesel, gasoline, workshop gases, lubricants and paints and solvents will be stored on site during construction. The potential for impacts to the environment and the public are likely to be minimal.

No acutely hazardous/flammable materials will be handled in bulk during the construction phase. Natural gas will be supplied on an as required basis once the power plant is running. Other requirements such as the water treatment chemicals are only required in limited quantities and there is no requirement for a massive build-up of inventory in the run-up to commissioning.

The CTT is located adjacent to the CPF and its associated wellfield, which are operational sites and these will continue to produce natural gas. A loss of containment from either of these sources could impact on the construction site (domino effect), but there is insufficient information to assess the cumulative risk, at this stage. It is however noted that the route of the proposed natural gas line crosses one of the existing lines to the gas wells.

Table 23:Sasol CTT Project Impact Assessment – construction phase

Indicator of potential impact	Pre-mitigation					Post-mitigation				
	Magnitude	Duration	Geographic Extent	Probability	Significance	Magnitude	Duration	Geographic Extent	Probability	Significance
Small amounts of hazardous materials such as diesel and petrol for vehicles.	1	1	2	2	**Negligible** 8	1	1	1	2	**Negligible** 6

11.3.2 Operational phase impacts

The operational impacts commence with the onset of commissioning. There have been a number of incidents related to natural gas piping systems and their start-up and commissioning of equipment. Commissioning marks the transition from construction to normal operation and may involve abnormal activities. Incidents may arise during commissioning that could impact the safety and health of the public, and potentially delay the project e.g. the “blow down” incident at a natural gas power plant undergoing commissioning in Middleton, Connecticut during 2010. This practice, although common, is inherently unsafe. The United States Chemical Safety board strongly cautions natural gas power plants against the venting of high-pressure natural gas in or near work sites.

The venting of gas is also a practice that is practiced during ahead of routine maintenance and extended shutdowns. This must be done so as to ensure that the flammable gas is not vented close to ignition sources or workers.

Hazardous materials (natural gas) will be transported to and combusted at the gas power plant (two alternatives considered). The plant requirements for natural gas will be achieved by operating a natural gas pipeline from the existing Sasol CPF, to the power plant. No natural gas will be stored at the CTT site. Losses of containment of natural gas from the underground gas fuel pipeline and power plant process piping/equipment could result in releases of flammable gas under pressure, with the following potential impacts:

- Jet fires;
- Flash fires;
- Vapour cloud explosions.

Areas of confinement such as engine/turbine halls are potential areas where fugitive natural gas can from leaks and other losses of containment can accumulate producing potentially explosive atmospheres. Engineering controls based on recognised safety standards and practices are required to be put in place to mitigate against this type of event.

Methane is also a powerful greenhouse gas which can contribute to the longer-term impacts of global warming and there is a concern that losses due to leaks, venting, and flaring from operating natural gas plants are higher than are being reported. In order to deliver on the promise of cleaner energy, methane emissions due to leaks, venting and flaring need to be kept to a minimum. Leaks and deliberate purging of methane for maintenance e.g. when the HRSG taken off-line (open circuit) operation are also potential sources of fires and explosions.

Table 24: Sasol CTT Project Impact Assessment - operational phase

Indicator of potential impact	Pre-mitigation					Post-mitigation				
	Magnitude	Duration	Geographic Extent	Probability	Significance	Magnitude	Duration	Geographic Extent	Probability	Significance
Impact of a loss of containment of natural gas during commissioning leading to dispersion, ignition and flash fire or explosive effects	8	1	2	1	**Negligible 11**[1]	6	2	2	1	**Negligible 8**
Impact of an Explosion in a building. Failure to implement adequate engineering controls to	8	1	2	1	**Negligible 11**	6	2	2	1	**Negligible 8**

Indicator of potential impact	Pre-mitigation					Post-mitigation				
	Magnitude	Duration	Geographic Extent	Probability	Significance	Magnitude	Duration	Geographic Extent	Probability	Significance
prevent a confined space explosion										
Impact of jet fires full bore rupture of incoming natural gas line with flammable vapour dispersion, ignition and flash fire or explosive effects	8	1	2	1	**Negligible 11**	6	2	2	1	**Negligible 8**

[1] **Whilst it may appear as if some of these impacts are trivial, it must be borne in mind that this may be ascribed to the misalignment of the duration of events and allocation of probability. Durations and risks are allocated in seconds, minutes and hours i.e. small fractions of hours and seconds.**

11.3.3 Decommissioning phase impacts

Once the facility is decommissioned all activities will cease. There is a requirement to minimise the risk of environmental impacts that may result from the decommissioning and closure of the site. On decommissioning the use of natural gas to produce power would be discontinued. The power plant be drained of gas and water treatment chemicals, cleaned and dismantled, as per the closure plan.

12.0 ENVIRONMENTAL ACTION PLAN

Table 25: Environmental Action Plan

Aspect	Potential Impact	Impact Source	Detailed Actions	Responsibility
Construction Phase – no major offsite impacts to neighbours and local communities				
Operational Phase				
Confined space explosion	Building Explosion	Natural gas leaks accumulated in buildings	Risk assessments, hazardous area classifications, ventilation studies and plant audits	Proponent, Design/ Project team.
Natural gas loss of containment	Flammable vapour dispersion, ignition and flash fire or explosive effects	Lack of carefully considered commissioning procedures leading to unplanned/uncontrolled losses of containment of natural gas.	Detailed commissioning plan and risk assessment	Proponent

Aspect	Potential Impact	Impact Source	Detailed Actions	Responsibility
Natural gas loss of containment	flammable vapour dispersion, ignition and flash fire or explosive effects	Full bore rupture of natural gas line	Safe emergency shutdown valving systems, gas detection, alarm and executive function systems to limit the amount of vapour that's released	Proponent, Design/ Project team
Decommissioning Phase - None identified not in scope				

13.0 MONITORING PROGRAMME

Table 26: Monitoring Programme

Objective	Detailed Actions	Monitoring Location	Frequency	Responsibility
Construction Phase – no specific requirements identified				
Operational Phase				
Monitoring and alarming of gas levels in confined plant spaces	Identification of confined spaces and installation of gas detection and alarming devices. Monitoring of the effectiveness of ventilation systems	Confined spaces such as turbine enclosures and engine rooms	Ongoing, hourly	Proponent
Monitoring of effectiveness of dirty water treatment processes to prevent egress from the plant	Installation of sampling and measurement protocols	Site boundaries	Ongoing, reviewed annually	Proponent
Decommissioning Phase – no specific requirements identified				

14.0 CONCLUSIONS

This risk assessment was performed with the assumption that the site would be maintained to an acceptable level and that all statutory regulations would be applied. It was also assumed that the detailed engineering designs would be done by competent people and would be correctly specified for the intended duty. For example, it was assumed that tank wall thicknesses have been correctly calculated, that vents have been sized for emergency conditions, that instrumentation and electrical components comply with the specified electrical area classification, that material of construction is compatible with the products, etc.

It is the responsibility of the owners and their contractors to ensure that all engineering designs would have been completed by competent persons and that all pieces of equipment would have been installed correctly.

A number of incident scenarios were simulated, considering the prevailing meteorological conditions, and as described in the report. Furthermore, the following conclusions are made:

14.1 Fires

Jet and flash fires could result from a loss of containment during the pipeline transfer (under pressure) of natural gas from the CPF to the gas turbines/engines located at the CTT.

The 1% fatality (10 kW/m^2 for jet fires) and the flash fire envelope for the metering and pressure reduction stations extend a short distance beyond the site boundary, further analysis was conducted to access whether there would be any differentiation between the CCGT and OCGE on the basis of the specific technology.

14.2 Vapour Cloud Explosions

Vapour cloud explosions could result from a loss of containment during the pipeline transfer (under pressure) of natural gas from the CPF to the gas turbines/engines located at the CTT. Vapour clouds during loss of containment incidents onsite could drift off site to explode some distance away once they encounter an ignition source.

The 1% fatality isopleth (usually accepted as an overpressure of 0.1 bar) for some incidents involving natural gas do extend a short distance beyond the northern site boundary.

14.3 Combined and Societal Risks

The combined risk isopleth of 1 x 10^{-6} fatalities per person per year isopleth extends beyond the site boundary, for a short distance.

The 3 x 10^{-7} fatalities per person per year risk isopleth considered for the purposes of town planning did extend beyond the plant boundary. than at the site boundary. The risks to the public would be considered at the lower ALARP range and considered tolerable based on the criteria applied in this report.

14.4 Impact Assessment

An impact assessment based on the results of this study was conducted. The various impacts were assessed, and each was found to have LOW SIGNIFICANCE, pre and post mitigation. While the severity of the impacts is considered high, the probability of the impact offset this risk, leading to the Low Significance ranking.

14.5 Impacts onto Neighbouring Properties

Impacts could extend beyond the site boundary to the north of the facility, into the area (500 m) allowed in the design for separation between the CCT and CPF. These areas appear to comprise of largely uninhabited areas of natural vegetation. The potential does however exist for fires at the CTT to generate bush fires that could cover a large area and affect the CPF.

The CTT will have little or no impact on the CPF although there is potential for some interaction where the CTT natural gas line crosses one of the pipelines that feed the CPF from the wellfields.

These remaining areas currently appear to be sparsely populated naturally vegetated and largely rural with some rain based “slash and burn” agricultural practices in place. These areas are sufficiently far removed from the CTT site to be unaffected by fires or explosions at the CTT.

15.0 RECOMMENDATIONS

RISCOM did not find any fatal flaws that would prevent the project proceeding to the detailed engineering phase of the project. RISCOM would support the project with the following conditions:

- Compliance with all statutory requirements and applicable standards and codes including specific requirements such as ISO/CD 21789 (risk assessments for gas turbine plants, etc.);
- Incorporation of applicable guidelines or equivalent international recognised codes of good design and practice into the final designs;
- A recognised process hazard analysis (HAZOP, FMEA, etc.) Should be completed for the proposed facility prior to construction to ensure design and operational hazards have been identified and adequate mitigation put in place;
- Compliance with IEC 61508 and IEC 61511 (Safety Instrument Systems) standards, or equivalent, to ensure adequate protective instrumentation is included in the design and would remain valid for the full life cycle of the plant (the designer should demonstrate that sufficient and reliable instrumentation would be specified and installed on the power station);
- Compliance with all statutory requirements and applicable standards and codes;
- Demonstration by the Proponent or its contractor that the final designs would reduce the risks posed by the installation to internationally acceptable guidelines;
- Completion of an emergency preparedness and response document for on-site and off-site scenarios
- Permission not being granted for increases to the product list or product inventories without redoing part of or the full ESIA.

16.0 SPECIALIST RECOMMENDATION

As a result of the risk assessment study conducted for the proposed CTT Gas Power Plant Facility located near Inhassoro, some of events were found to have risks beyond the site boundary. It is not however anticipated that these will impact significantly on the public due to the low population density in the vicinity of the facility and the extent and nature of the impacts.

Identified risks fall into the ALARP range with the potential for reduction. The mitigation measures proposed in this report should be considered for implementation, if not already in place.

RISCOM has not found sufficient differentiation between the proposed technology solutions (Closed Circuit Gas Turbine and Open Circuit Gas Engine) based on community safety/quantitative risk assessment to decide either way and have not expressed a specific preference for either technology.

The available information allows a medium confidence level in the assessment. This is based on the information provided being at a detailed conceptual level, which has the potential for changes during implementation and construction. Typically, a high level of confidence would only be assigned based on a review of designs that are finalised for construction.

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Signature Page

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Note: *DISCLAIMER: This report was prepared by RISCOM (PTY) LTD. The material in it reflects the best judgement of RISCOM (PTY) LTD in light of the information available to it at the time of preparation. Any use that a third party makes of this report, or any reliance on or decisions to be based on it, are the responsibility of such third parties. RISCOM (PTY) LTD accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.*

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APPENDIX A

Riscom Accreditation and Specialist Details

RISCOM (PTY) LTD

RISCOM (PTY) LTD is a consulting company that specialises in process safety. Further to this, RISCOM[5] is an approved inspection authority (AIA) for conducting Major Hazard Installation (MHI) risk assessments in accordance with the OHS Act 85 of 1993 and its Major Hazard Installation regulations (July 2001). In order to maintain the status of approved inspection authority, RISCOM is accredited by the South African National Accreditation System (SANAS) in accordance with the IEC/ISO 17020:2012 standard. The accreditation consists of a number of elements, including technical competence and third-party independence.

The independence of RISCOM is demonstrated by the following:

- RISCOM does not sell or repair equipment that can be used in the process industry;
- RISCOM does not have any shareholding in processing companies nor companies
- performing risk assessment functions;
- RISCOM does not design equipment or processes.

Mike Oberholzer is a professional engineer, holds a Bachelor of Science in Chemical Engineering and is an approved signatory for MHI risk assessments, thereby meeting the competency requirements of SANAS for assessment of the risks of hazardous components, including fires, explosions and toxic releases.

M P Oberholzer Pr. Eng. BSc (Chem. Eng.) MIChemE MSAIChE

Ian Ralston is a professional engineer, holds a Bachelor of Science in Chemical Engineering and has prepared this specialist report.

I**.D Ralston Pr. Eng. BSc (Chem. Eng.) FSAIMM MIChemE MSAIChE**

5 RISCOM™ and the RISCOM logo are trademarks of RISCOM (PTY) LTD

Department of Labour Approved Inspection Authority

labour

Department:
Labour
REPUBLIC OF SOUTH AFRICA

National Department of Labour
Republic of South Africa

APPROVED INSPECTION AUTHORITY

Registered in accordance with the provisions of the Occupational Health and Safety Act, Act 85 of 1993, as amended and the Major Hazard Installation Regulations.

This is to certify that:

RISCOM (PTY) LTD

has been registered by the Department of Labour as an Approved Inspection Authority: Type A, to conduct Major Hazard Installation Risk Assessment, in terms of Regulation 5(5)(a), of the Major Hazard Installation Regulations.

CONDITIONS OF REGISTRATION:

- The AIA must at all time comply with the requirements of the Occupational Health and Safety Act, Act 85 of 1993, as amended.
- This registration certificate is not transferable.
- This registration will lapse if there is a name change of the AIA or change in ownership.

CHIEF INSPECTOR

Valid from: **27 May 2017**
Expires: **26 May 2021**
Certificate Number: **CI MHI 0005**

SANAS Accreditation Certificate and Schedule

sanas
South African National Accreditation System

CERTIFICATE OF ACCREDITATION

In terms of section 22(2)(b) of the Accreditation for Conformity Assessment, Calibration and Good Laboratory Practice Act, 2006 (Act 19 of 2006), read with sections 23(1), (2) and (3) of the said Act, I hereby certify that:-

RISCOM (PTY) LTD
Co. Reg. No.: 2002/019697/07
JOHANNESBURG

Facility Accreditation Number: **MHI0013**

is a South African National Accreditation System accredited Inspection Body to undertake **TYPE A** inspection provided that all SANAS conditions and requirements are complied with

This certificate is valid as per the scope as stated in the accompanying schedule of accreditation, Annexure "A", bearing the above accreditation number for

THE ASSESSMENT OF RISK ON MAJOR HAZARD INSTALLATIONS

The facility is accredited in accordance with the recognised International Standard

ISO/IEC 17020:2012

The accreditation demonstrates technical competency for a defined scope and the operation of a management system

While this certificate remains valid, the Accredited Facility named above is authorised to use the relevant SANAS accreditation symbol to issue facility reports and/or certificates

Mr R Josias
Chief Executive Officer

Effective Date: 27 May 2017
Certificate Expires: 26 May 2021

This certificate does not on its own confer authority to act as an Approved Inspection Authority as contemplated in the Major Hazard Installation Regulations. Approval to inspect within the regulatory domain is granted by the Department of Labour.

ANNEXURE A

SCHEDULE OF ACCREDITATION

Facility Number: MHI0013

TYPE A

Permanent Address: Riscom (Pty) Ltd 33 Brigish Dr Northcliff Johannesburg 2195 Tel: (011) 431-2198 Fax: 086 624 9423 Mobile: 082 457 3258 E-mail: mike@riscom.co.za	**Postal Address:** P O Box 2541 Cresta Johannesburg 2195 Issue No.: 13 Date of issue: 27 May 2017 Expiry date: 26 May 2021	
Nominated Representative: Mr MP Oberholzer	**Quality Manager:** Mr MP Oberholzer **Technical Manager:** Mr MP Oberholzer	**Technical Signatory:** Mr MP Oberholzer
Field of Inspection	**Service Rendered**	**Codes and Regulations**
Regulatory: 1) Explosive chemicals 2) Gases: i) Flammable Gases ii) Non-flammable, non toxic gases (asphyxiants) iii) Toxic gases 3) Flammable liquids 4) Flammable solids, substances liable to spontaneous combustion, substances that on contact with water release flammable gases 5) Oxidizing substances and organic peroxides 6) Toxic liquids and solids	Specific Services: i) Frequency/ Probability Analysis ii) Consequence Modelling iii) Hazard Identification and Analysis including HAZARD and Operability studies (HAZOP) iv) Emergency planning reviews	Programmes, guidelines, regulations and codes: MHI regulation par. 5 (5) (b) Reference Manual Bevi Risk Assessments version 3.2 (2009) CPR 18E (1999), Guideline for quantitative risk assessment ("Purple Book"), TNO Apeldoorn. CPR 14E (1997). Methods for the Calculation of Physical Effects ("Yellow Book"), 3rd Edition, TNO, Apeldoorn. CPR 16E (1992). Methods for the Determination of Possible Damage ("Green Book"), 1st Edition, TNO, Apeldoorn. Lees FP (2001). Loss Prevention in the Process Industries: Hazard Identification, Assessment and Control, 2nd Edition, Butterworths, London, UK.

Original date of accreditation: 27 May 2005

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ISSUED BY THE SOUTH AFRICAN NATIONAL ACCREDITATION SYSTEM

Accreditation Manager

APPENDIX B

Physical Properties

NATURAL GAS MODELLED AS METHANE

Methane Constants

Constant	Unit	Value
Acentric Factor		0.01155
Critical Pressure	bar	45.99
Critical Temperature	°C	-82.6
Emissive Power Length Scale	m	6.75
Enthalpy Interpolation Range	°C	0
Heat of Combustion	kJ/kmol	8.03E+05
Heat of Solution	kJ/kg	0
Laminar Burning Velocity	m/s	0.45
Liquid Water Surface Tension	dyne/cm	50
Lower Flammability Limit	ppm	4.40E+04
Maximum Burn Rate	$kg/m^2{\cdot}s$	0.141
Maximum Surface Emissive Power	kW/m^2	220
Melting Point	°C	-182.5
Molecular Weight		16.04
Normal Boiling Point	°C	-161.5
Pool Fire Burn Rate Length	m	7.25
Solubility in Water		0
TNT Explosion Efficiency	%	0
Triple Point Pressure	bar	0.117
Triple Point Temperature	°C	-182.5
Upper Flammability Limit	ppm	1.65E+05

Methane Coefficients

Parameter	Equation Number	Lower Temp. Limit (°C)	Upper Temp. Limit (°C)	Coefficient A	Coefficient B	Coefficient C	Coefficient D	Coefficient E
Vapour Viscosity	102	-182.5	726.9	5.26E-07	0.5901	105.7	0	
Vapour Thermal Conductivity	102	-182.5	726.9	6325	0.4304	7.70E+08	-3.87E+10	
Vapour Pressure	101	-182.5	-82.59	39.2	-1324	-3.437	3.10E-05	2
Trimer Coefficients	101			0	0	0	0	0
Surface Tension	106	-182.5	-82.59	0.03656	1.147	0	0	0
Second Virial Equation Coefficient	104	-162.3	1227	0.05108	-25.18	-2.56E+05	5.98E+15	-5.77E+17
Saturated Liquid Density	105	-182.5	-82.59	2.921	0.2898	190.6	0.2888	
Octamer Coefficients	101			0	0	0	0	0
Liquid Viscosity	101	-182.5	-85.15	-6.157	178.2	-0.9524	-9.06E-24	10
Liquid Thermal Conductivity	100	-182.5	-93.15	0.4177	-0.00245	3.56E-06	0	0
Liquid Heat Capacity	114	-182.5	-83.15	65.71	3.89E+04	-257.9	614.1	0
Ideal Gas Heat Capacity	107	-223.1	1227	3.33E+04	7.99E+04	2087	4.16E+04	992
Hexamer Coefficients	101			0	0	0	0	0
Dimer Coefficients	101			0	0	0	0	0

APPENDIX C

Reference Drawings

Drawings relevant to the two technology alternatives are listed below and attached as part of this Appendix.

Closed Circuit Gas Turbines

Closed Circuit Gas Turbines Reference Drawings

Drawing No.	Title	Rev
MGTP-F1-PIP-01-01	CCGT Power Plant Preliminary Plot Plan	Rev 2
MGTP-F1-HSE-01-01	CCGT Power Plant Preliminary Hazardous Area Classification	Rev 0

Open Circuit gas engines

Open Circuit Gas Engine Reference Drawings

Drawing No.	Title	Rev
MGTP-F1-PIP-01-02	OCGE Alternative Preliminary Plot Plan	Rev 1
MGTP-F1-HSE-01-01	OCGE Alternative Preliminary Hazardous Area Classification	Rev 0

APPENDIX D

Generic Equipment Failures

In order to characterise various failure events and assign a failure frequency, fault trees were constructed starting with a final event and working from the top down to define all initiating events and frequencies. Unless otherwise stated, analysis was completed using published failure rate data (RIVM 2009). Equipment failures can occur in tanks, pipelines and other items handling hazardous chemical components. These failures may result in:

a) Release of combustible, flammable and explosive components with fires or explosions upon ignition;

b) Release of toxic or asphyxiant components.

Storage Vessels

Scenarios involving storage vessels can include catastrophic failures that would lead to leakage into the bund with a possible bund fire. A tank-roof failure could result in a possible tank-top fire. The fracture of a nozzle or transfer pipeline could also result in leakage into the bund.

Typical failure frequencies for atmospheric and pressure vessels are listed in the following two tables.

Failure frequencies for atmospheric vessels

Event	Leak Frequency (per item per year)
Small leaks	1×10^{-4}
Severe leaks	3×10^{-5}
Catastrophic failure	5×10^{-6}

Failure frequencies for pressure vessels

Event	Failure Frequency (per item per year)
Small leaks	1×10^{-5}
Severe leaks	5×10^{-7}
Catastrophic failure	5×10^{-7}

TRANSPORT AND PROCESS PIPING

Piping may fail as a result of corrosion, erosion, mechanical impact damage, pressure surge (water hammer) or operation outside the design limitations for pressure and temperature. Failures caused by corrosion and erosion usually result in small leaks, which are easily detected and corrected quickly. For significant failures, the leak duration may be from 10 – 30 minutes before detection.

Generic data for leak frequency for process piping is generally expressed in terms of the cumulative total failure rate per year for a 10 m section of pipe for each pipe diameter. Furthermore, failure frequency normally decreases with increasing pipe diameter. Scenarios and failure frequencies for a pipeline apply to pipelines with connections, such as flanges, welds and valves.

The failure data in the table below represents the total failure rate, incorporating all failures of whatever size and due to all probable causes. These frequencies are based on an assumed environment where no excessive vibration, corrosion, erosion or thermal cyclic stresses are expected. For incidents causing significant leaks (such as corrosion), the failure rate will be increased by a factor of 10.

Failure frequencies for process pipes

Description	Frequencies of Loss of Containment for Process Pipes (per meter per year)	
	Event	**Failure Frequency (per item per year)**
	Full Bore Rupture	**Leak**
Nominal diameter < 75 mm	1×10^{-6}	5×10^{-6}
75 mm < nominal diameter < 150 mm	3×10^{-7}	2×10^{-6}
Nominal diameter > 150 mm	1×10^{-7}	5×10^{-7}

For scenarios and failure frequencies no distinction is made between process pipes and transport pipes, the materials from which a pipeline is made, the presence of cladding, the design pressure of a pipeline or its location on a pipe bridge. However, a distinction is made between aboveground pipes and underground pipes. The scenarios for aboveground pipes are given in the next table and the those for underground pipes in the table after that.

Transport pipelines aboveground can be compared, under certain conditions, with underground pipes in a pipe bay. The necessary conditions for this are external damage being excluded, few to no flanges and accessories present and the pipe is clearly marked. In very specific situations the use of a lower failure frequency for transport pipes aboveground can be justified.

Failure frequencies for aboveground transport pipelines

Description	Frequency (per meter per annum)		
	Nominal Diameter < 75 mm	**75 mm > Nominal Diameter > 150 mm**	**Nominal Diameter > 150 mm**
Full bore rupture	1×10^{-6}	3×10^{-7}	1×10^{-7}
Leak with an effective diameter of 10% of the nominal diameter, up to a maximum of 50 mm	5×10^{-6}	2×10^{-6}	5×10^{-7}

Failure frequencies for underground transport pipelines

Description	Frequency (per meter per annum)		
	Pipeline in Pipe Lane[6]	Pipeline Complies with NEN 3650	Other Pipelines
Full bore rupture	7×10^{-9}	1.525×10^{-7}	5×10^{-7}
Leak with an effective diameter of 20 mm	6.3×10^{-8}	4.575×10^{-7}	1.5×10^{-6}

PUMPS AND COMPRESSORS

Pumps can be subdivided roughly into two different types, reciprocating pumps and centrifugal pumps. This latter category can be further subdivided into canned pumps (seamless pumps) and gasket (pumps with seals). A canned pump can be defined as an encapsulated pump where the process liquid is located in the space around the rotor (impeller), in which case gaskets are not used. Compressors can also be subdivided roughly into reciprocating compressors and centrifugal compressors.

Failure rates for pumps and compressors are given in the following two tables.

Failure frequency for centrifugal pumps and compressors

Event	Canned (No Gasket) Frequency (per annum)	Gasket Frequency (per annum)
Catastrophic failure	1.0×10^{-5}	1.0×10^{-4}
Leak (10% diameter)	5.0×10^{-5}	4.4×10^{-3}

Failure frequency for reciprocating pumps and compressors

Event	Frequency (per annum)
Catastrophic failure	1.0×10^{-4}
Leak (10% diameter)	4.4×10^{-3}

6A pipeline located in a 'lane' is a pipeline located with a group of pipelines on a dedicated route. Loss-of-containment frequencies for this situation are lower because of extra preventive measures.

LOADING AND OFFLOADING

Loading can take place from a storage vessel to a transport unit (road tanker, tanker wagon or ship) or from a transport unit to a storage vessel. The failure frequencies for loading and offloading arms are given in the table below.

Failure frequencies for loading and offloading arms and hoses

Event	Frequency (per hour)	
	Loading and Offloading Arms	**Loading and Offloading Hoses**
Rupture	3×10^{-8}	4×10^{-6}
Leak with effective diameter at 10% of nominal diameter to max. 50 mm	3×10^{-7}	4×10^{-5}

ROAD OR RAIL TANKERS WITHIN THE ESTABLISHMENT

Road or rail tankers are transport vehicles with fixed and removable tanks. In addition, they include battery wagons and, insofar as these are fitted on a transport vehicle, tank containers, swap-body tanks and MEGCs (multiple element gas containers).

The failure rate of tankers on an establishment is dependent on the pressure rating of the tank and is given in the next two tables.

Failure frequencies for road tankers with an atmospheric tank

Event	Frequency (per annum)
Instantaneous release of the entire contents	1×10^{-5}
Release of contents from the largest connection	5×10^{-7}

Failure frequencies for road tankers with a pressurised tank

Event	Frequency (per annum)
Instantaneous release of the entire contents	1×10^{-7}
Release of contents from the largest connection	5×10^{-7}

It should be noted that no scenarios are included for loss of containment as a result of external damage to tanker or fire in the surrounding areas. It is assumed that sufficient measures are taken to prevent external damage to the tanker.

HUMAN FAILURE

Human error and failure can occur during any life cycle or mode of operation of a facility. Human failure can be divided into the following categories:

i) Human failure during design, construction and modification of the facility;

ii) Human failure during operation and maintenance;

iii) Human failure due to errors of management and administration.

Human failure during design, construction and modification is part of the generic failure given in this subsection. Human failure due to errors of organisation and management are influencing factors. Some of the types of tasks that have been evaluated for their rates of human failure are given in the table below.

Human failure rates of specific types of tasks (CPR 12E 2005; Red Book)

Tasks	Human Failure (events per year)
Totally unfamiliar, performed at speed with no real idea of likely consequences	0.55
Failure to carry out rapid and complex actions to avoid serious incident such as an explosion	0.5
Complex task requiring high level of comprehension and skill	0.16
Failure to respond to audible alarm in control room within 10 minutes	1.0×10^{-1}
Failure to respond to audible alarm in quiet control room by some more complex action such as going outside and selecting one correct value among many	1.0×10^{-2}
Failure to respond to audible alarm in quiet control room by pressing a single button	1.0×10^{-3}
Omission or incorrect execution of step in a familiar start-up routine	1.0×10^{-3}
Completing a familiar, well-designed, highly-practiced, routine task occurring several times per hour, performed to highest possible standards by a highly-motivated, highly-trained and experienced person totally aware of implications of failures, with time to correct potential error but without the benefit of significant job aids	4.0×10^{-4}

IGNITION PROBABILITY OF FLAMMABLE GASES AND LIQUIDS

Estimation of probability of an ignition is a key step in assessment of risk for installations where flammable liquids or gases are stored. There is a reasonable amount of data available relating to characteristics of ignition sources and effects of release type and location.

Probability of ignition for stationary installations is given in the first following table (along with classification of flammable substances in the next table). These can be replaced with ignition probabilities related to surrounding activities. For example, probability of a fire from a flammable release at an open flame would increase to a value of 1.

Probability of direct ignition for stationary installations (RIVM 2009)

Substance Category	Source-Term Continuous	Source-Term Instantaneous	Probability of Direct Ignition
Category 0 Average to high reactivity	< 10 kg/s 10 – 100 kg/s > 100 kg/s	< 1000 kg 1000 – 10 000 kg > 10 000 kg	0.2 0.5 0.7
Category 0 Low reactivity	< 10 kg/s 10 – 100 kg/s > 100 kg/s	< 1000 kg 1000 – 10 000 kg > 10 000 kg	0.02 0.04 0.09
Category 1	All flow rates	All quantities	0.065
Category 2	All flow rates	All quantities	0.0043[7]
Category 3 Category 4	All flow rates	All quantities	0

Classification of flammable substances

Substance Category	Description	Limits
Category 0	Extremely flammable	Liquids, substances and preparations that have a flashpoint lower than 0°C and a boiling point (or the start of the boiling range) less than or equal to 35°C Gaseous substances and preparations that may ignite at normal temperature and pressure when exposed to air
Category 1	Highly flammable	Liquids, substances and preparations that have a flashpoint of below 21°C
Category 2	Flammable	Liquids, substances and preparations that have a flashpoint equal to 21°C and less than 55°C
Category 3		Liquids, substances and preparations that have a flashpoint greater than 55°C and less than or equal to 100°C
Category 4		Liquids, substances and preparations that have a flashpoint greater than 100°C

7This value is taken from the CPR 18E (Purple Book; 1999). RIVM (2009) gives the value of delayed ignition as zero. RISCOM (PTY) LTD believes the CPR 18E is more appropriate for warmer climates and is a conservative value.

APPENDIX E

Assessment Methodology and Rating Criteria

Potential impacts are assessed according to the direction, intensity (or severity), duration, extent and probability of occurrence of the impact. These criteria are discussed in more detail below:

Direction of an impact may be positive, neutral or negative with respect to the particular impact. A positive impact is one which is considered to represent an improvement on the baseline or introduces a positive change. A negative impact is an impact that is considered to represent an adverse change from the baseline or introduces a new undesirable factor.

Intensity/Severity is a measure of the degree of change in a measurement or analysis (e.g. the concentration of a metal in water compared to the water quality guideline value for the metal), and is classified as none, negligible, low, moderate or high. The categorisation of the impact intensity may be based on a set of criteria (e.g. health risk levels, ecological concepts and/or professional judgment). The specialist study must attempt to quantify the intensity and outline the rationale used. Appropriate, widely-recognised standards are used as a measure of the level of impact.

Duration refers to the length of time over which an environmental impact may occur: i.e. transient (less than 1 year), short-term (1 to 5 years), medium term (6 to 15 years), long-term (greater than 15 years with impact ceasing after closure of the project) or permanent.

Scale/Geographic extent refers to the area that could be affected by the impact and is classified as site, local, regional, national, or international. The reference is not only to physical extent but may include extent in a more abstract sense, such as an impact with regional policy implications which occurs at local level.

Probability of occurrence is a description of the probability of the impact actually occurring as improbable (less than 5% chance), low probability (5% to 40% chance), medium probability (40% to 60% chance), highly probable (most likely, 60% to 90% chance) or definite (impact will definitely occur).

Impact significance will be rated using the scoring system shown in table below. The significance of impacts is assessed for the two main phases of the project: i) construction ii) operations. While a somewhat subjective term, it is generally accepted that significance is a function of the magnitude of the impact and the likelihood (probability) of the impact occurring. Impact magnitude is a function of the extent, duration and severity of the impact, as shown in the following table.

Scoring system for evaluating impacts

Severity	Duration	Extent	Probability
10 (Very high/don't know)	5 (Permanent)	5 (International)	5 (Definite/don't know)
8 (High)	4 (Long-term – longer than 15 years and impact ceases after closure of activity)	4 (National)	4 (Highly probable)
6 (Moderate)	3 (Medium-term- 6 to 15 years)	3 (Regional)	3 (Medium probability)
4 (Low)	2 (Short-term - 1 to 5 years)	2 (Local)	2 (Low probability)
2 (Minor)	1 (Transient – less than 1 year)	1 (Site)	1 (Improbable)
1 (None)			0 (None)

After ranking these criteria for each impact, a significance rating was calculated using the following formula:

- **SP (significance points) = (severity + duration + extent) x probability.**

The maximum value is 100 significance points (SP). The potential environmental impacts were then rated as of High (SP >75), Moderate (SP 46 – 75), Low (SP ≤15 - 45) or Negligible (SP < 15) significance, both with and without mitigation measures in accordance with **Table 27**.

Table 27: Impact significance rating

Value	Significance	Comment
SP >75	Indicates **high** environmental significance	Where an accepted limit or standard may be exceeded, or large magnitude impacts occur to highly valued/sensitive resource/receptors. Impacts of high significance would typically influence the decision to proceed with the project.
SP 46 - 75	Indicates **moderate** environmental significance	Where an effect will be experienced, but the impact magnitude is sufficiently small and well within accepted standards, and/or the receptor is of low sensitivity/value. Such an impact is unlikely to have an influence on the decision. Impacts may justify significant modification of the project design or alternative mitigation.
SP 15 - 45	Indicates **low** environmental significance	Where an effect will be experienced, but the impact magnitude is small and is within accepted standards, and/or the receptor is of low sensitivity/value or the probability of impact is extremely low. Such an impact is unlikely to have an influence on the decision although impact should still be reduced as low as possible, particularly when approaching moderate significance.
SP < 15	Indicates **negligible** environmental significance	Where a resource or receptor will not be affected in any material way by a particular activity or the predicted effect is deemed to be imperceptible or is indistinguishable from natural background levels. No mitigation is required.
+	**Positive impact**	Where positive consequences / effects are likely.

In addition to the above rating criteria, the terminology used in this assessment to describe impacts arising from the current project are outlined in the below table. In order to fully examine the potential changes that the project might produce, the project area can be divided into Areas of Direct Influence (ADI) and Areas of Indirect Influence (AII).

- Direct impacts are defined as changes that are caused by activities related to the project and they occur at the same time and place where the activities are carried out i.e. within the ADI.
- Indirect impacts are those changes that are caused by project-related activities but are felt later in time and outside the ADI. The secondary indirect impacts are those which are as a result of activities outside of the ADI.

Types of impact

Term for Impact Nature	Definition
Direct impact	Impacts that result from a direct interaction between a planned project activity and the receiving environment/receptors (i.e. between an effluent discharge and receiving water quality).
Indirect impact	Impacts that result from other activities that are encouraged to happen as a consequence of the Project (i.e., pollution of water placing a demand on additional water resources).
Cumulative impact	Impacts that act together with other impacts (including those from concurrent or planned activities) to affect the same resources and/or receptors as the Project.

APPENDIX F

Material Safety Data Sheets

NATURAL GAS COMPOSITION

The composition of the natural gas as detailed in the conceptual study is reflected in table below.

Natural Gas Composition

Component	Formula	Volume (% v/v)
Nitrogen	N_2	1.16
Methane	CH_4	94.90
Ethane	C_2H_4	1.85
Propane	C_3H_6	0.85
Butane	C_4H_{10}	0.50
Pentane	C_5H_{12}	0.16
Hexane	C_6H_{14}	0.06
Heptane	C_7H_{16}	0.06
Water	H_2O	0.00
Total		**100.00**

NATURAL GAS MATERIAL SAFETY DATA SHEET

APPENDIX G

SENSITIVE RECEPTORS

1.0 SENSITIVE RECEPTORS

A total of 1,982 points of interest were considered, including nine sensitive receptors [1], 16 residential areas, 18 industrial areas and 1,939 individual structures (Table 6, **Figure 10**).

Table 6: Sensitive receptors and points of interest.

#	Type	Receptor	UTM 36 K X (m)	UTM 36 K Y (m)
1	Sensitive	Health Centre - Mangungumete	716678	7596975
2		Health Centre - Temane	708403	7594925
3		Orphanage	713951	7594566
4		Primary school - Mangugumete	717059	7596101
5		Primary School - Temane	707567	7593872
6		Primary school - Chitsotso	718704	7586374
7		School - Litlau	716490	7599301
8		School - Manusse	707125	7585185
9		School - Temane Base Camp	716319	7598164
10	Residential	Chipongo	733081	7588874
11		Chitsotso	718703	7586373
12		Inhassoro	728432	7616428
13		Litlau	716489	7599300
14		Mabime	724375	7598565
15		Macovane	712561	7621798
16		Maimelane	716715	7602127
17		Mangarelane I	732540	7602476
18		Mangarelane II	726915	7606638
19		Mangugumete	717058	7596101
20		Manusse	707124	7585184
21		Mapanzene	731881	7593751
22		Temane	707566	7593872
23		Temane Base Camp	716319	7598164
24		Vilanculos	738891	7566447

#	Type	Receptor	UTM 36 K X (m)	UTM 36 K Y (m)
25		Vulanjane	716275	7606606
26	Industrial / AQ monitoring	T-03 Well Pad	715875	7598067
27		T-04 Well Pad	710139	7587132
28		T-05 Well Pad	712686	7595239
29		T-06 Well Pad	705906	7596210
30		T-07 Well Pad	711231	7598913
31		T-10 Well Pad	710866	7597158
32		T-12 Well Pad	715408	7595830
33		T-13 Well Pad	716227	7599871
34		T-15 Well Pad	713449	7593189
35		T-16 Well Pad	707703	7598230
36		T-23 Well Pad	717065	7593814
37	Industrial	CTT	713149	7591987
38		CPF	713078	7593356
39		Proposed Well Pad	708543	7595056
40		Proposed Well Pad	709134	7588475
41		Electricidade de Moçambique	713937	7594344
42		Proposed Well Pad	706425	7582122
43		Proposed Well Pad	709363	7578786

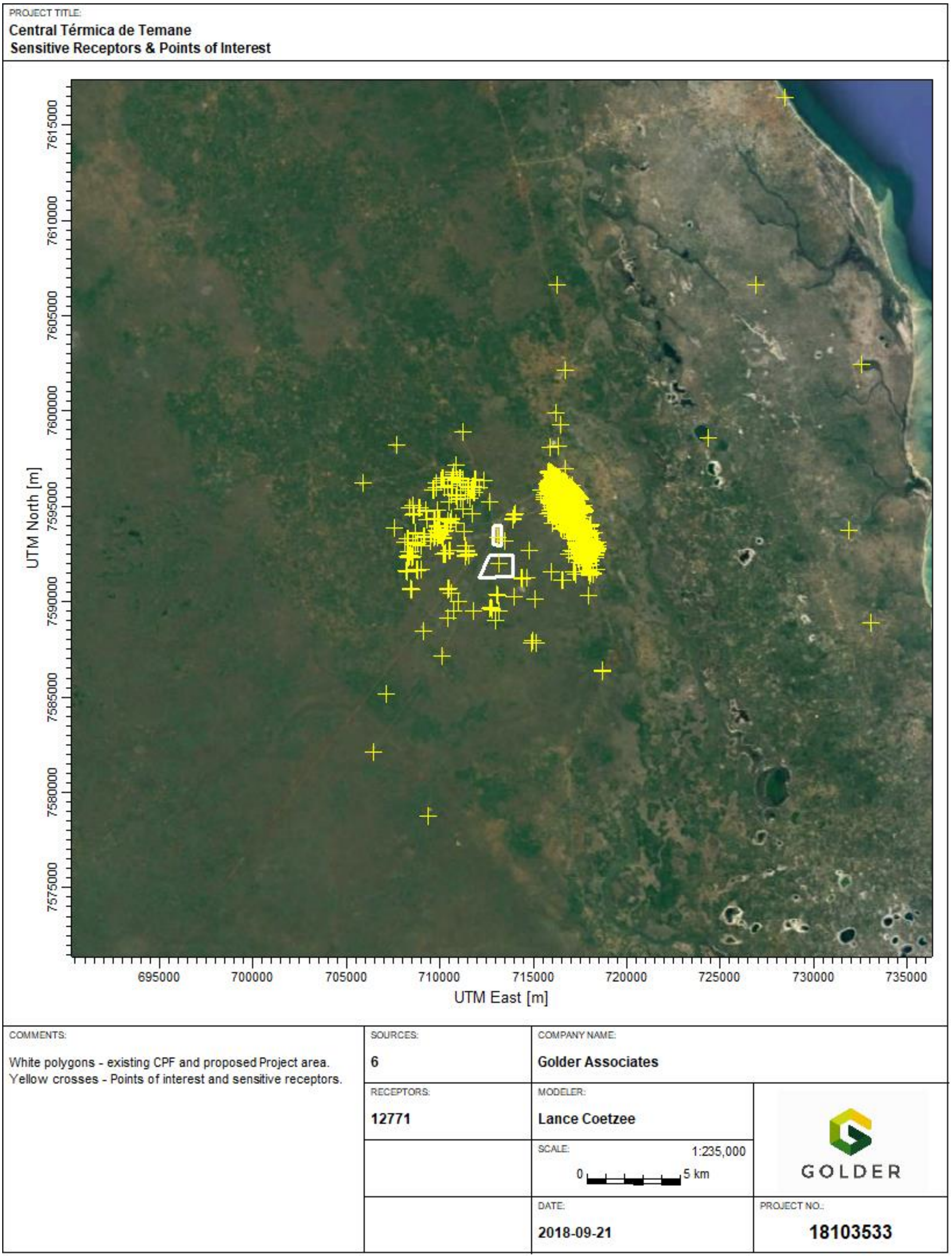

Figure 10: Points of interest and sensitive receptors

APPENDIX H

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Document Limitations

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