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QUANTITATIVE RISK ASSESSMENT OF THE PROPOSED IMPORTATION AND DISTRIBUTION OF LIQUID NATURAL GAS (LNG) INTO THE COEGA SPECIAL ECONOMIC ZONE

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RISCOM (PTY) LTD

RISCOM (PTY) LTD is a consulting company that specialises in process safety. Further to this, RISCOM* 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.

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- 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.

Opinions and interpretations expressed herein this report are outside the scope of SANAS accreditation.

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QUANTITATIVE RISK ASSESSMENT OF THE PROPOSED IMPORTATION AND DISTRIBUTION OF LIQUID NATURAL GAS (LNG) INTO THE COEGA SPECIAL ECONOMIC ZONE

EXECUTIVE SUMMARY

1 INTRODUCTION

The Coega Development Corporation (hereinafter referred to as CDC) wishes to develop a gas to power project, including three power plants and associated infrastructure, within the Coega Special Economic Zone Coega SEZ.

The overall project would broadly involve the following components:

1. A Liquefied Natural Gas (LNG) terminal, consisting of a berth with off-loading arms within the Port of Ngqura, cryogenic pipelines, storage and handling facilities and re-gasification modules (both on and off-shore) - the subject of this EIA;
2. Gas pipelines and distribution hub, for the transmission, distribution and reticulation of natural gas within the Coega SEZ and Port of Ngqura - the subject of this EIA;
3. Three Gas to Power plants, each with a 1000 MW generation capacity (specific generation technologies may vary); and,
4. Electricity transmission lines to evacuate electricity to the previously approved 400 kV lines in the SEZ.

The ultimate/ overall proposed project will comprise of three power plants with power generation capacities of 1000 MW each. A total power generation capacity of up to 3000 MW will therefore be available once the full extent of the project has been developed (which may be spread over a number of phases) the timing of which is unknown at this stage and is dependent on the CDC securing successful bidders for each component of the development.

Four separate EIA applications have been lodged of the project (each of the three power plants and one for the gas infrastructure). This approach allows for the transfer of discrete projects and associated authorisations to developers following a bidding process.

The purpose of this report is to convey the essential details, which include a short description of hazards, the receiving environment and current relevant design as well as risks and consequences of a major incident for the gas distribution portion of the project., excluding the respective power plants.

1.1 Terms of Reference

The main aim of the investigation was to quantify the risks to employees, neighbours and the public with regard to the proposed CDC LNG facility in the Coega SEZ. The terms of reference include:

1. Develop accidental spill and fire scenarios for the facility;
2. Using generic failure rates, determine the probability of each scenario identified, as well as potential consequences;
3. Where the consequence / risk will extend beyond the site boundary, calculate the maximum individual risk, taking into account generic failure rates, initiating events, meteorological conditions and lethality;
4. Determine and comment on the societal risk posed by the facility;
5. Recommend mitigation measures to minimise risk where required; and
6. Identify and assess impacts, including cumulative impacts of the project.

This risk assessment is not intended to replace an MHI risk assessment nor any other legal requirement.

1.2 Purpose and Main Activities

The main activity at the proposed CDC LNG facility in the Coega SEZ would be the importation, storage and regasification of LNG from shipping carriers. The stored LNG would either be transported to the nearby power stations via pipeline of loaded into road tankers for delivery to end users.

1.3 Main Hazards Due to Substance and Process

The main hazards that would occur with a loss of containment of hazardous components at the proposed CDC LNG facility in the Coega SEZ include exposure to:

- Thermal radiation from fires;
- Overpressure from explosions.

2 ENVIRONMENT

The proposed CDC LNG importation and gas distribution hub, is shown in Figure 2-1. LNG would be imported at the deep-water Port of Ngqura and transported via pipeline to the adjacent Coega SEZ.

The Coega SEZ is 11,500 ha in extent and situated approximately 40 km north of Port Elizabeth in the Eastern Cape province of South Africa. The Coega SEZ is bounded by the N2 highway to the west and the Indian Ocean to the east.

The Coega SEZ has full access control, preventing unauthorised entry. To this end, only people with valid reasons (workers) will get access to the Coega SEZ. The general public will be located outside of the boundary of the Coega SEZ. Thus, the Coega SEZ is an industrially zoned area with no institutions with occupancy by vulnerable populations e.g., young, elderly, sick and handicapped people. All people within the Coega SEZ will be adults that will be trained on the surrounding dangers, emergency plans, wear applicable PPE and can evade/escape local dangers.

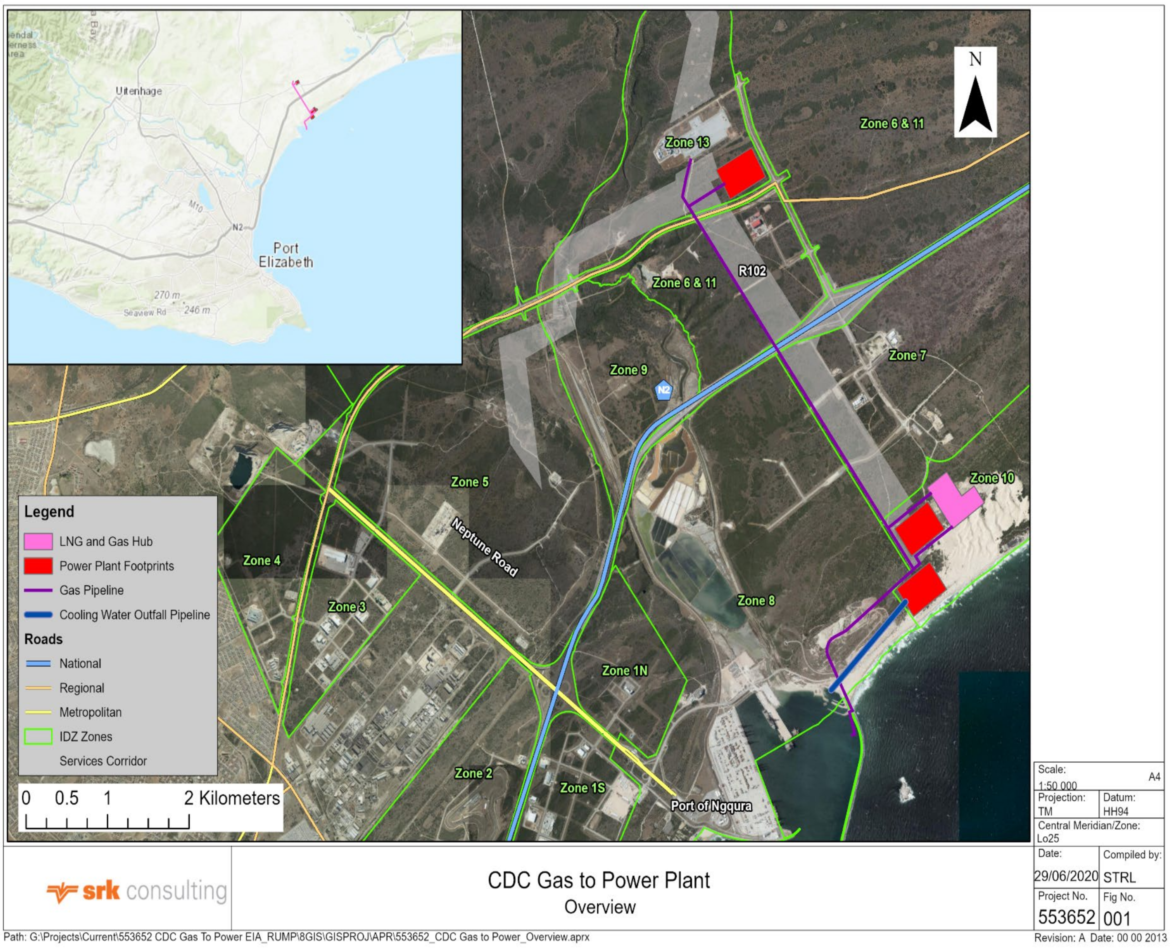

Figure 2-1: Site locality map for the gas infrastructure, with the power plant footprints shown in red for context (courtesy SRK)

3 PROCESS DESCRIPTION

3.1 Site

The project is planned over two phases, as shown in the simplified flow diagram shown in Figure 3-1.

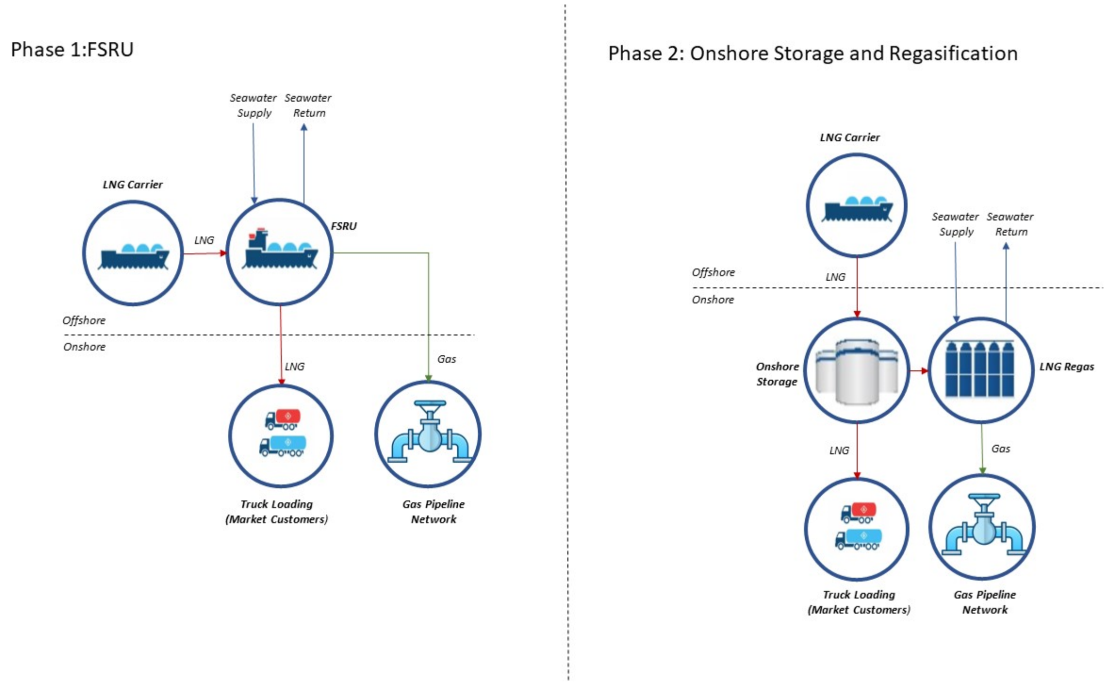

Figure 3-1: Simplified flow diagram of the project process phase

The first phase would involve the importation of LNG from LNG carriers and storing the product in an LNG Floating Storage and Regasification Unit (FSRU), berthed at the Port of Ngqura. Once the offloading of LNG from the carrier, the carrier will then depart the port. The LNG at the FSRU will then store sufficient LNG to continue operations, until the next shipment arrives. There will be up to two FSRUs berthed at the Port of Ngura for operation purposes.

The FSRU will have a regasification unit, which will allow the option to convert the refrigerate LNG, to a gaseous form, by heating the LNG above its boiling point. Once heated, the LNG is no longer a liquid and becomes natural gas (NG) or compressed natural gas (CNG) depending on the storage or transportation pressure. The NG could be sent to the gas hub power stations. A second cryogenic line will transport LNG to the hub for the filling of road tankers. The locality of this phase is shown in Figure 3-2.

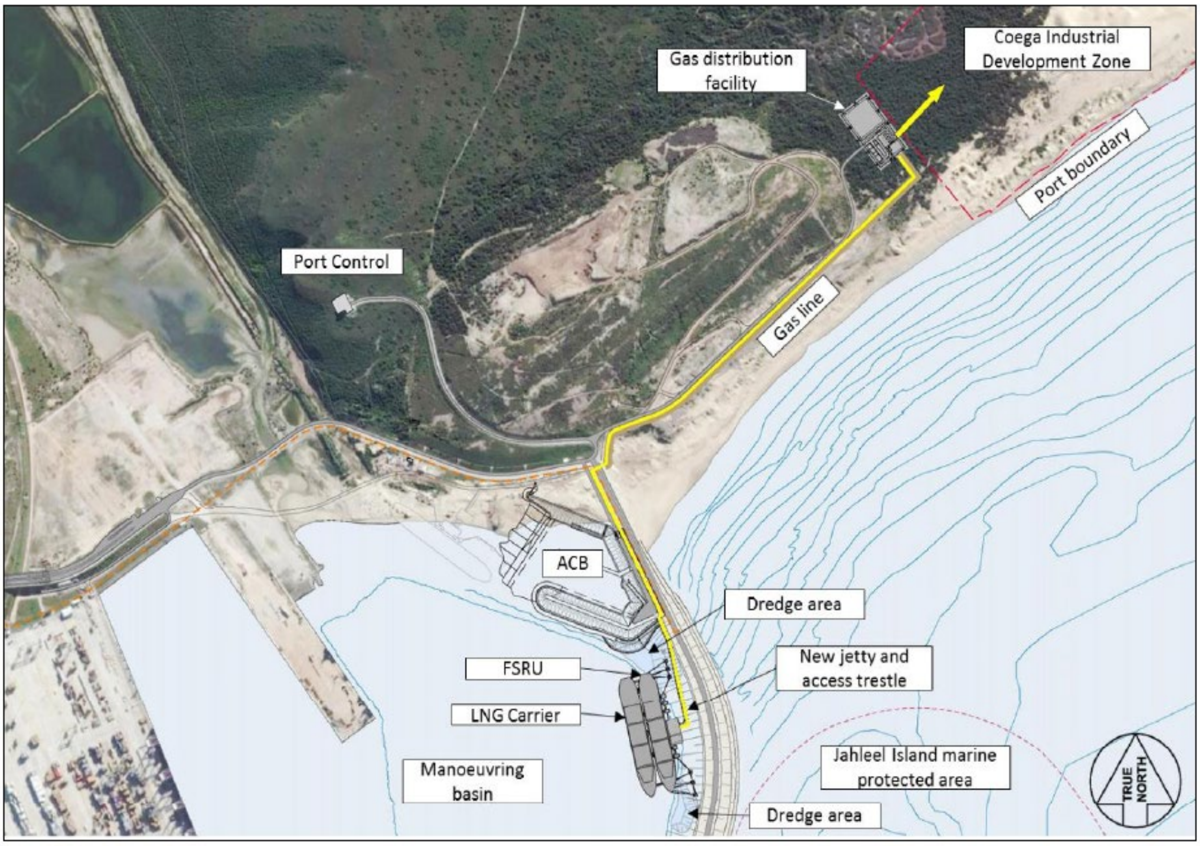

Figure 3-2: Proposed Phase 1 location and pipeline alignment from the LNG carrier to the gas distribution facility (Source: SRK)

The second phase would be the construction of a cryogenic LPG storage on the land, extending the gas distribution facility / gas hub. In this phase, the LNG would be offloaded from the carrier and transported via a cryogenic pipeline to the on-shore storage. The regasification would take place on shore and the NG would be transported via a cryogenic pipeline to the respective power plants and the cryogenic LNG used to fill road tankers. The locality of this phase is shown in Figure 3-3.

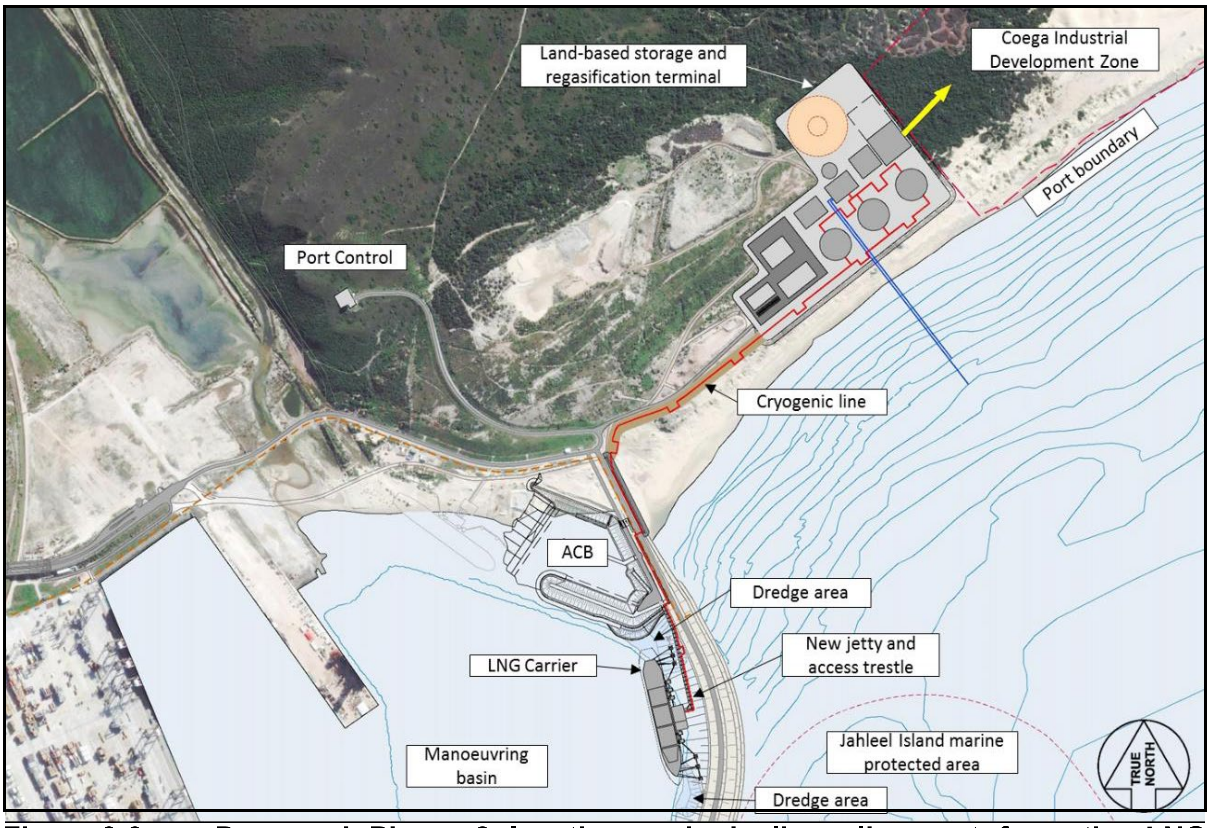

Figure 3-3: Proposed Phase 2 location and pipeline alignment from the LNG carrier to the gas distribution facility (Source: SRK)

3.2 Process Description

Natural gas consists mostly of methane, which is a flammable gas at atmospheric conditions. Economical transportation of natural gas would require liquefying the gas so that it would occupy less volume by weight. There are two methods to liquefy natural gas, the first being to compress the gas to a sufficiently high pressure that the gas would remain a liquid and the second way is to reduce the temperature to about -162°C (at mean sea level). The term liquid natural gas (LNG) refers to the liquid state at -162°C. When the LNG is regasified into a vapour state, it is no longer a liquid and referred to a natural gas (NG). When the natural gas is compressed to above its critical pressure of about 46 bar it becomes a supercritical fluid and referred to as compressed natural gas (CNG).

3.3 Summary of Bulk Materials to be Stored on Site

A summary of bulk materials that can give hazardous effects that are to be stored on site is given in Table 3-1.

Table 3-1: Summary of hazardous components to be stored on site

No.	Component	CAS No.	Inventory	Comment
1	LNG	74-82-8	170 000 m^3	FSRU - Phase 1
2	LNG	74-82-8	2 x 160 000 m^3	Storage - Phase 2

4 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 considerations are taken into account:

- Chemical identities;
- Location of on-site installations that use, produce, process, transport or store hazardous components;
- Type and design of containers, vessels or pipelines;
- Quantity of material that could be involved in an airborne release;
- Nature of the hazard most likely to accompany hazardous materials spills or releases, e.g., airborne toxic vapours or mists, fires or explosions, large quantities to be stored and certain handling conditions of processed components.

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.

SANS 1461 (2018) is based on RIVM (2009) for process plants. The latter standards describe the minimum scenarios to be included in the assessment, as well as the assumptions to be used. As full compliance of SANS 1461 (2018) cannot be achieved within the NEMA legislative framework, general compliance of the aforementioned standards at this stage would be applicable and briefly described in the sections below. This general compliance assessment constitutes a quantitative risk assessment (QRA).

The QRA process 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 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), taking into account all generic failure rates, initiating events (such as ignition), meteorological conditions and lethality.

Scenarios included in this QRA have impacts external to the establishment. 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.

5 CONCLUSIONS

Risk calculations are not precise. Accuracy of predictions is determined by the quality of base data and expert judgements.

This risk assessment included the consequences of fires and explosions at the CDC facility in the Coega SEZ. A number of well-known sources of incident data were consulted and applied to determine the likelihood of an incident to occur.

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. All designs should be in full compliance with (but not limited to) the Occupational Health and Safety Act 85 of 1993 and its regulations, the National Buildings Regulations and the Buildings Standards Act 107 of 1977 as well as local bylaws.

A number of incident scenarios were simulated, taking into account the prevailing meteorological conditions, and described in the report.

5.1 Notifiable Substances

The General Machinery Regulation 8 and its Schedule A on notifiable substances requires any employer who has a substance equal to or exceeding the quantity listed in the regulation to notify the divisional director. A site is classified as a Major Hazard Installation if it contains one or more notifiable substances or if the off-site risk is sufficiently high. The latter can only be determined from a quantitative risk assessment.

Methane (compressed) is listed as a notifiable substance at a threshold value of 15 t. The schedule does not specifically mention LNG. Furthermore, the storage of LNG would be in the liquid state and not compressed. To this end LNG would not be classified as a notifiable substance.

However, if the design changes so that more than 15 t of CNG would be contained in a single container, the CNG would be classified as a notifiable substance and the facility would automatically be classified as a Major Hazard Installation.

5.2 Phase 1

Phase 1 would consist of an LNG carrier offloading LNG into a Floating Storage and regasification unit (FSRU) From the FSRU, LNG would be transported via a pipeline to the gas distribution facility to load road tankers. Part of the LNG at the FSRU would be regasified into the gas phase and transported to the power stations.

The design has not been completed and thus this design assumed:

- the LNG would be transported in a 24” NB pipeline at 10 bar;
- the compressed natural gas (CNG) would be transported at 0ºC at 60 bar within a 24” NB pipeline.

The potential amount of released material that should be considered as a result of a collision is 126 m^3 in 1800 seconds for a large release (RIVM 2009).

In the worst case, the expected 10 kW/m2 thermal radiation from LNG pool fires on the ocean extend to a maximum distance of 366 m with a full-bore failure of the delivery hose.

An accidental jet fire from the CNG gas pipeline on the ship regasification and compression could have substantial reach and depending on the orientation and point of release. It is assumed that the ship designers would make provision to prevent ship damage from a jet fire.

The release from an LNG pipeline, under low wind speeds could result in significant end point impacts. This is mainly due to the evaporation of cold LNG released onto the ground above the pipeline.

Releases from high pressure CNG pipelines produce a high momentum jet with no significant vapour clouds. Due to the vertical release, the impacts would be limited, with the greatest impact occurring during high wind seeds.

The risks from the Phase 1 will remain within the Port of Ngqura and the Coega SEZ and would not impact the general public outside of this area.

As the cold vent designs have not been completed, the thermal radiation from fires cannot be assessed.

It is common practice to place pipelines within common servitudes. ASME B31.8 Paragraph 841.143 suggests a minimum clearance of a 6” between the pipeline and any other structure.

A literature search did not find any scientific relationship to the minimum distance between adjacent pipelines. Of more importance is the construction and maintenance of such pipelines, bearing in mind that third-party interference resulting in damaged pipelines with injuries and losses is the greatest cause of pipeline failures. For this reason, it is suggested that placing pipelines on top of each other should be avoided and that crossover pipelines be designed and installed with caution.

For new gas transmission pipelines, one should consider a separate adjacent lane with sufficient distance between the lanes for safe construction and maintenance of the pipelines. The distance would be specified by the width of the vehicles involved in such activities.

It is important to note that the maintenance of the pipeline is not limited to construction but also includes inspections. It would be expected that specified vehicles may traverse the length of the transmission pipelines for the observation of leaks or dangers posed to the pipeline. For this reason, an adjacent vehicle lane would be required possibly situated between the gas pipeline and other fuel pipelines.

5.3 Phase 2

The Phase 2 would replace the FSRU with two large storage facilities located at the gas distribution facility. The regasification and unit would also be relocated from the FSRU to the gas distribution centre.

The extent from fires and explosions could extend considerable distances, particularly at low windspeeds. However, the risks from Phase 2 would remain within the Port of Ngqura and the Coega SEZ and would not impact the general public outside of this area. For this reason, the project would not be considered a Major Hazard Installation.

The risks from Phase 2 would result reduces risks at the jetty, but increased risks at the gas distribution centre. It should however be noted that the risks from Phase 1 would not be considered unacceptable.

As the cold vent designs have not been completed, the thermal radiation from fires cannot be assessed.

5.4 Coega SEZ Proposed Power Plant and Gas Distribution Hub Consolidated Risks

The impacts described in this report are specific to the proposed gas distribution from the port of Port of Ngqura to the power plants via cryogenic or compressed natural pipeline.

The four new land-based power plants are shown in have been proposed for the Coega SEZ and consist of the following:

- Power plant in Zone 10 South;
- Power Plant in Zone 10 North;
- Power plant in Zone 13;
- Engie Power Plant; and,
- Gas distribution hub.

The proposed KarPower installation will consist of up to two power ships moored in the Port of Ngqura. A FSRU will be associated with the power ships to provide the fuel. An LNG carrier will replenish the FSRU fuel on a regular basis. The electricity generated will be sent to the Dedisa substation connecting the national grid.

The existing Dedisa Peaking Power Plant operates on diesel fuel. While diesel can burn, the impacts of fires will be limited to the immediate vicinity of the installation.

The impacts from the KarPower power plant have been qualitatively assessed, resulting in no significant onshore consequences.

The consolidation of the powerplants and gas hub would not significantly change the individual risks of the individual projects, as presented in the various reports. Furthermore, the combined projects risks, would not alter the outcome of the individual site risk, regarding the acceptability or the project related to the public and workers.

5.5 Major Hazard Installation

It should be noted that Section 2 of the MHI regulations applies only if the risk posed by the installation poses a risk to both employees and the public. The definition of an employee under the OHS Act No. 85 of 1993 is that an employee receives remuneration and works under supervision. As all personnel entering the greater complex do so at the access point and have business within the secured boundaries of the complex, such personnel would be considered employees under that definition.

The risk of $1x10^{-6}$ fatalities per person per year isopleth for modelled releases on site does not extend beyond the Coega SEZ boundary. As the general public is located beyond the complex boundary, the proposed operations would not pose a risk to both employees and the public.

This investigation concluded that under the current design conditions the proposed transmission and distribution pipelines would not be considered as a Major Hazard Installation.

This study is not intended to replace the Major Hazard Installation risk assessment which should be completed prior to construction of the terminal.

5.6 Land Planning

In accordance with Section 9 the MHI regulations, no facility within the $3x10^{-7}$ fatalities per person per year isopleths should be approved without first evaluating the impacts on the proposed development or potential land usage. Acceptable developments can be verified in the tables provided in the HSE Land Use Planning Methodology (UK 2011), attached in Appendix D.

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QUANTITATIVE RISK ASSESSMENT OF THE PROPOSED IMPORTATION AND DISTRIBUTION OF LIQUID NATURAL GAS (LNG) INTO THE COEGA SPECIAL ECONOMIC ZONE

1 INTRODUCTION

The Coega Development Corporation (hereinafter referred to as CDC) wishes to develop a gas to power project, including three power plants and associated infrastructure, within the Coega Special Economic Zone Coega SEZ.

The overall project would broadly involve the following components:

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The ultimate/ overall proposed project will comprise of three power plants with power generation capacities of 1000 MW each. A total power generation capacity of up to 3000 MW will therefore be available once the full extent of the project has been developed (which may be spread over a number of phases) the timing of which is unknown at this stage and is dependent on the CDC securing successful bidders for each component of the development.

Four separate EIA applications have been lodged of the project (each of the three power plants and one for the gas infrastructure). This approach allows for the transfer of discrete projects and associated authorisations to developers following a bidding process.

The purpose of this report is to convey the essential details, which include a short description of hazards, the receiving environment and current relevant design as well as risks and consequences of a major incident for the gas distribution portion of the project., excluding the respective power plants.

1.1 Legislation

Legislation discussed in this subsection is limited to the health and safety of employees and the public.

Risk assessments are conducted when required to do so by law or by companies wishing to determine the risks of the facility for other reasons, such as insurance. In South Africa, risk assessments are carried out under the legislation of two separate acts, each with different requirements. These are discussed in the subsections that follow.

1.1.1 National Environmental Management Act (No. 107 of 1998) (NEMA) and its Regulations

The National Environmental Management Act (NEMA) contains South Africa's principal environmental legislation. It has as its primary objective to make provision for cooperative governance by establishing principles for decision making on matters affecting the environment, on the formation of institutions that will promote cooperative governance and on establishing procedures for coordinating environmental functions exercised by organs of state as well as to provide for matters connected therewith (Government Gazette 1998).

Section 30 of the NEMA act deals with the control of emergency incidents where an "*incident*" is defined as an "*unexpected sudden occurrence, including a major emission, fire or explosion leading to serious danger to the public or potentially serious pollution of or detriment to the environment, whether immediate or delayed*".

The act defines "*pollution*" as *"any change in the environment caused by:*

(i) Substances;
(ii) Radioactive or other waves; or
(iii) Noise, odours, dust or heat…

Emitted from any activity, including the storage or treatment of waste or substances, construction and the provision of services, whether engaged in by any person or an organ of state, where that change has an adverse effect on human health or wellbeing or on the composition, resilience and productivity of natural or managed ecosystems, or on materials useful to people, or will have such an effect in the future... "

"*Serious*" is not fully defined but would be accepted as having long lasting effects that could pose a risk to the environment or to the health of the public that is not immediately reversible.

This is similar to the definition of a MHI as defined in the Occupational Health and Safety Act (OHS Act) 85 of 1993 and its MHI regulations.

Section 28 of NEMA makes provision for anyone who causes pollution or degradation of the environment being made responsible for the prevention of the occurrence, continuation or reoccurrence of related impacts and for the costs of repair of the environment. In terms of the provisions under Section 28 that are stated as:

" Every person who causes, has caused or may cause significant pollution or degradation of the environment must take reasonable measures to prevent such pollution or degradation from occurring, continuing or recurring, or, in so far as such harm to the environment is authorised by law or cannot reasonably be avoided or stopped… "

1.1.2 The Occupational Health and Safety Act No. 85 of 1993

The Occupation Health and Safety Act 85 (1993) is primarily intended for the health and safety of the employees, whereas its MHI regulations is intended for the health and safety of the public.

The OHS Act shall not apply in respect of:

“ a) *A mine, a mining area or any works as defined in the Minerals Act, 1991 (Act No. 50 of 1991), except in so far as that Act provides otherwise;*

b) *Any load line ship (including a ship holding a load line exemption certificate), fishing boat, sealing boat and whaling boat as defined in Section 2 (1) of the Merchant Shipping Act, 1951 (Act No. 57 of 1951), or any floating crane, whether or not such ship, boat or crane is in or out of the water within any harbour in the Republic or within the territorial waters thereof, (date of commencement of paragraph (b) to be proclaimed.), or in respect of any person present on or in any such mine, mining area, works, ship, boat or crane.* ”

1.1.2.1 Major Hazard Installation Regulations

The MHI regulations (July 2001) published under Section 43 of the OHS Act require employers, self-employed persons and users who have on their premises, either permanently or temporarily, a major hazard installation or a quantity of a substance which may pose a risk (our emphasis) that could affect the health and safety of employees and the public to conduct a risk assessment in accordance with the legislation.

In accordance with legislation, the risk assessment must be done prior to construction of the facility by an approved inspection authority (AIA; see Appendix A and Appendix B), registered with the Department of Labour and accredited by the South African Accreditation Systems (SANAS).

Similar to Section 30 of NEMA as it relates to the health and safety of the public, the MHI regulations are applicable to the health and safety of employees and the public in relation to the operation of a facility and specifically in relation to sudden or accidental major incidents involving substances that could pose a risk to the health and safety of employees and the public.

It is important to note that the MHI regulations are applicable to the risks posed and not merely the consequences. This implies that both the consequence and likelihood of an event need to be evaluated, with the classification of an installation being determined on the risk posed to the employees and the public.

The definition of an employee under the OHS Act is a person that receives remuneration and works under supervision. As all personnel entering the complex do so at an access point and have business in the complex; such persons would be considered employees under the definition. This includes employees at the proposed CDC facility and other facilities located in the complex as well as contractors. The public would include persons located beyond the complex boundary.

The notification of the MHI is described in the regulations as an advertisement placement and specifies the timing of responses from the advertisement. It should be noted that the regulation does not require public participation.

The regulations, summarised in Appendix C, essentially consists of six parts, namely:

1. The duties for notification of a MHI (existing or proposed), including:
   a. Fixed;
   b. Temporary installations;
2. The minimum requirements for a quantitative risk assessment (QRA);
3. The requirements for an on-site emergency plan;
4. The reporting steps for risk and emergency occurrences;
5. The general duties required of suppliers;
6. The general duties required of local government.

As this is not an MHI risk assessment, the application of the above legislation is not mandatory but the legislation is described to give a background to this report.

1.1.3 National Ports Act (No. 12 of 2005)

The National Ports Act gives instruction to operations within the Ports Authority jurisdiction and includes the development of the port, provision of services and the control of operations within the port.

This proposed project clearly falls under the National Ports Act as per the definition of the act below:

> *" … 'port terminal' means terminal infrastructure, cargo-handling equipment, sheds and other land-based structures used for the loading, storage, transhipment and discharging of cargo or the embarkation and disembarkation of passengers… "*

The National Ports Act states that Transnet is responsible for the land development as well as the health and safety of people within the ports area.

1.1.4 Pressure Equipment Regulations

The pressure equipment regulations (PER) apply to the design, manufacture, operation, repair, modification, maintenance, inspection and testing of pressure equipment, with a design pressure equal to or greater than 50 kPa with view of health and safety.

1.1.4.1 SANS 347 Categorisation and Conformity Assessment Criteria for all Pressure Equipment

This standard specifies the criteria to be used for the categorization and conformity assessment of pressure equipment (metallic and non-metallic) for use by but not limited to the manufacturer, users, certification bodies and approved inspection authorities. This standard is also applicable to the certification, re-certification, modification or repair of pressure equipment (metallic and non-metallic), as defined by the relevant statutory regulations for pressure equipment. In Annex A of SANS 347:2012, there is a schedule of health and safety standards approved by the Department of Labour. Application of the selected health and safety standards in their entirety becomes mandatory under the provisions of the PER.

1.2 Terms of Reference

The main aim of the investigation was to quantify the risks to employees, neighbours and the public with regard to the proposed CDC LNG facility in the Coega SEZ. The terms of reference include:

1. Develop accidental spill and fire scenarios for the facility;
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1.3 Purpose and Main Activities

The main activity at the proposed CDC LNG facility in the Coega SEZ would be the importation, storage and regasification of LNG from shipping carriers. The stored LNG would either be transported to the nearby power stations via pipeline of loaded into road tankers for delivery to end users.

1.4 Main Hazards Due to Substance and Process

The main hazards that would occur with a loss of containment of hazardous components at the proposed CDC LNG facility in the Coega SEZ include exposure to:

- Thermal radiation from fires;
- Overpressure from explosions.

1.5 Assumptions and Limitations

The risk assessment was based on the conceptual designs of the LNG importation pipeline routing and gas distribution centre. Furthermore, EIAs are intended to suggest mitigation which may alter the design and layout of the project. It is thus understood that detail designs would be required to complete the project for construction.

RISCOM used the information provided and made engineering assumptions as described in the document. The accuracy of the document would be limited to the available documents presented in the Amendment Report.

The risk assessment excludes the following:

- Road transportation outside of the facility;
- Natural events such as earthquakes and floods;

- Ecological risk assessment;
- An emergency plan.

The methodology used and results generated from this study are intended as guidance for decision making relating to human health risks only, and should not be extended to wild or domestic animals.

1.6 Software

Physical consequences were calculated with TNO's EFFECTS v.9.0.23 and the data derived was entered into TNO's RISKCURVES v. 9.0.26 All calculations were performed by Mr M P Oberholzer.

2 ENVIRONMENT

2.1 General Background

The proposed CDC LNG importation and gas distribution hub, is shown in Figure 2-1. LNG would be imported at the deep-water Port of Ngqura and transported via pipeline to the adjacent Coega SEZ.

The Coega SEZ is 11,500 ha in extent and situated approximately 40 km north of Port Elizabeth in the Eastern Cape province of South Africa. The Coega SEZ is bounded by the N2 highway to the west and the Indian Ocean to the east.

The Coega SEZ has full access control, preventing unauthorised entry. To this end, only people with valid reasons (workers) will get access to the Coega SEZ. The general public will be located outside of the boundary of the Coega SEZ. Thus, the Coega SEZ is an industrially zoned area with no institutions with occupancy by vulnerable populations e.g., young, elderly, sick and handicapped people. All people within the Coega SEZ will be adults that will be trained on the surrounding dangers, emergency plans, wear applicable PPE and can evade/escape local dangers.

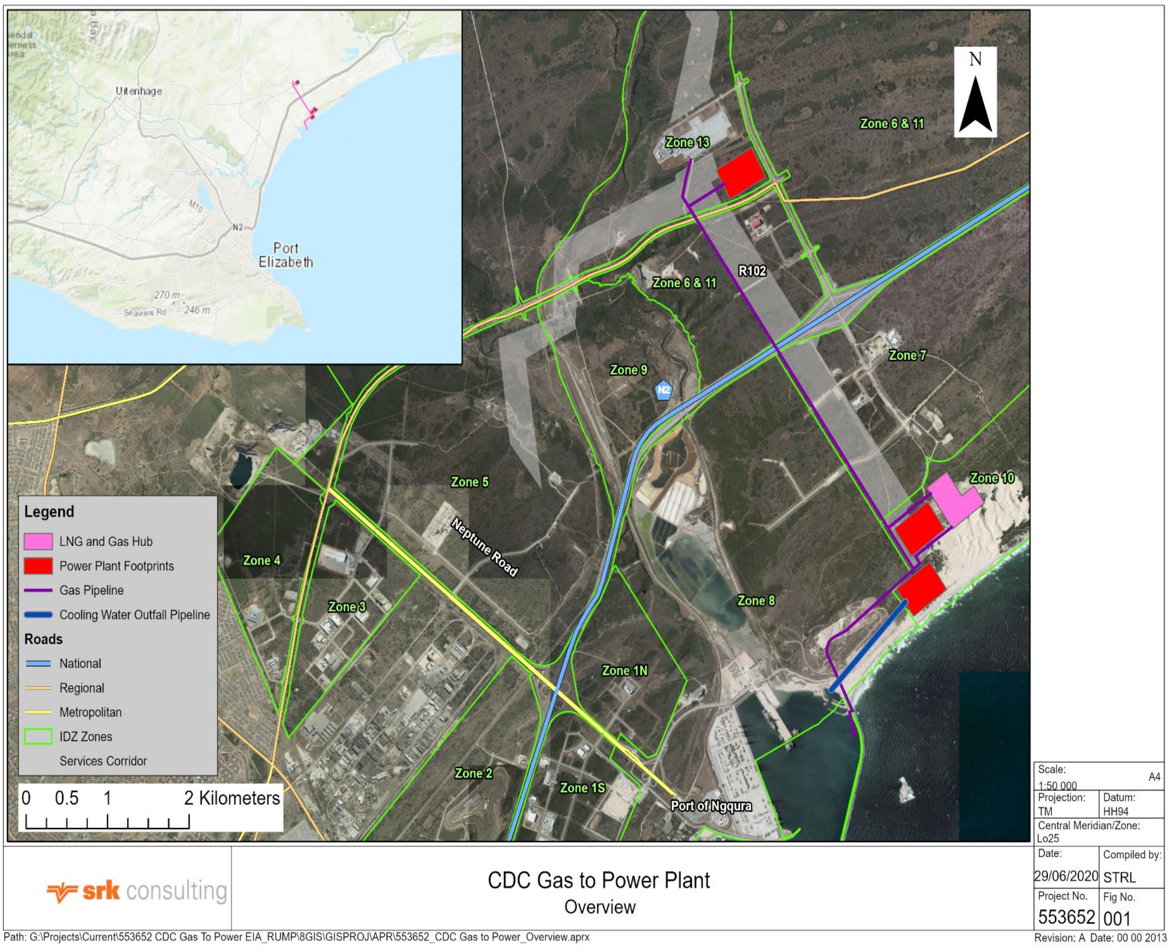


Figure 2-1: Site locality map for the gas infrastructure, with the power plant footprints shown in red for context (courtesy SRK)

2.2 Meteorology

Meteorological mechanisms govern dispersion, transformation and eventual removal of hazardous vapours from the atmosphere. The extent to which hazardous vapours 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 of vertical and horizontal components of motion. The stability and the depth of the atmosphere from the surface (known as the mixing layer) define the vertical component. The horizontal dispersion of hazardous vapours in the atmospheric boundary layer is primarily a function of wind field. Wind speed determines both the distance of downwind transport and the rate of dilution as a result of stretching of the plume, and generation of mechanical turbulence is a function of the wind speed in combination with surface roughness. Wind direction and variability in wind direction both determine the general path hazardous vapours will follow and the extent of crosswind spreading.

Concentration levels of hazardous vapours therefore fluctuate in response to changes in atmospheric stability, to concurrent variations in the mixing layer depth and to shifts in the wind field.

For this report, the meteorological conditions at Ngqura (Coega), as measured by the South African Weather Services, were used as the basis of hourly wind speed and direction determinations. Due to an incomplete weather set at Coega with no hourly readings after August 2015, the weather set comprised of four years from 1 January 2015 to 31 December 2019.

The long-term weather conditions at Port Elizabeth, as measured by the South African Weather Services, from 1981 to 2010 were used as the basis of, temperature, precipitation and atmospheric humidity and stability.

2.2.1 Surface Winds

Hourly averages of wind speed and direction recorded at Ngqura (Coega) were obtained from the South African Weather Services for the period from the 1st of January 2015 to the 31st of December 2019.

Ngqura (Coega) does not experience significant calm conditions, with the yearly average being 1.5%.

The wind roses in Figure 2-2 depict seasonal variances of measured wind speeds. In summer months, wind blows predominantly from the east with a frequency of 20%. High wind speeds are not uncommon, with medium windspeeds being more common.

During the winter months, the wind is predominantly from the north western quadrant with high frequency with medium to high wind speeds.

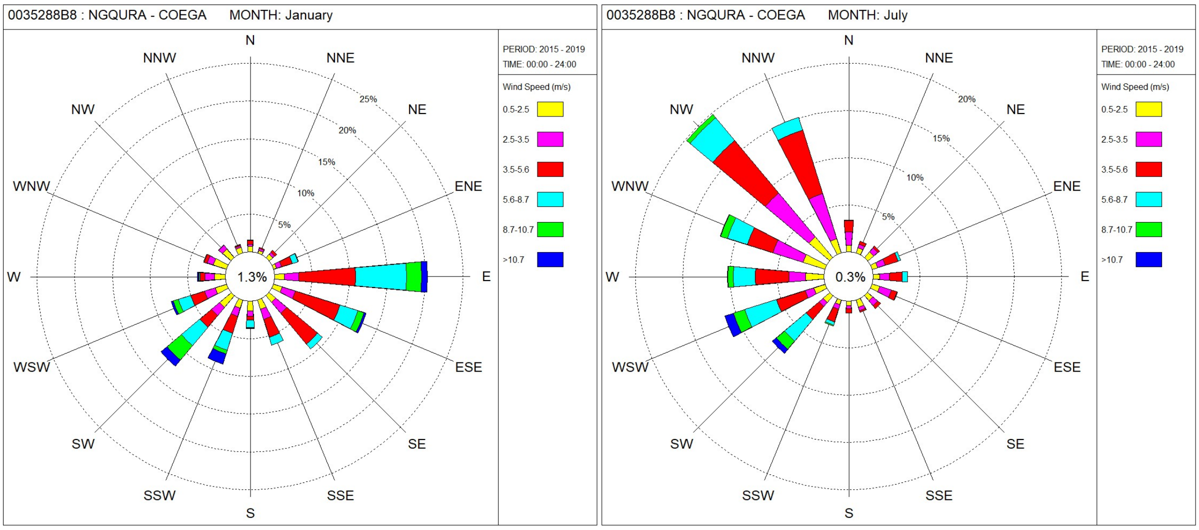


Figure 2-2: Seasonal wind speed as a function of wind direction at Ngqura (Coega) the period from 2015 to 2019

2.2.2 Precipitation and Relative Humidity

The long-term rainfall and relative humidity recorded at Port Elizabeth was obtained from the South African Weather Services for the period from 1981 to 2010, as given in Table 2-1.

In Port Elizabeth there is an average annual rainfall of 581 mm occurring throughout the year with no distinct winter or summer rainfall patterns.

The average relative humidity typically ranges from 61 % during the day to 82 % during the night time. There is no marked seasonal variance between the relative humidity ranges.

Table 2-1: Long-term rainfall at Port Elizabeth

Month	Average Maximum Relative Humidity (%)	Average Minimum Relative Humidity (%)	Average Monthly Precipitation (mm)
January	82	63	39
February	84	64	38
March	84	64	51
April	83	63	45
May	81	56	47
June	78	52	54
July	79	52	40
August	82	58	67
September	82	63	45
October	83	65	57
November	83	65	53
December	82	63	45
Year	**82**	**61**	**581**

2.2.3 Temperature

The long-term temperatures recorded at Port Elizabeth was obtained from the South African Weather Services for the period from 1981 to 2010, as given in Table 2-2.

The surrounding region has a temperate climate with the average daily maximum between 20°C and 25°C. Temperatures rarely extend below freezing, with the mean minimum average daily temperature of 13°C.

The diurnal temperature average was calculated to be 18°C, and liquid pool calculations were calculated with a temperature of 18°C.

Table 2-2: Long-term temperatures measured at Port Elizabeth

Month	Temperature (°C)			
	Highest Recorded	Average Daily Mean	Average Daily Maximum	Average Daily Minimum
January	37.3	21.6	25.6	17.6
February	37.6	21.9	25.9	17.9
March	39.6	20.6	24.7	16.4
April	40.1	18.7	23.4	14.0
May	36.9	16.8	22.1	11.4
June	32.4	14.5	20.5	8.6
July	33.1	14.2	20.2	8.2
August	34.4	14.8	20.0	9.6
September	39.0	15.7	20.3	11.0
October	39.1	17.1	21.2	13.1
November	38.2	18.7	22.7	14.6
December	36.0	20.3	24.3	16.2
Year	**40.1**	**17.9**	**22.6**	**13.2**

The measurements for the water temperature at Port Elizabeth shown in Figure 2-3 are provided by the daily satellite readings provided by the National Oceanic and Atmospheric Administration (NOAA). The temperatures given are the sea surface temperature (SST) which is most relevant to recreational users. The monthly values are:

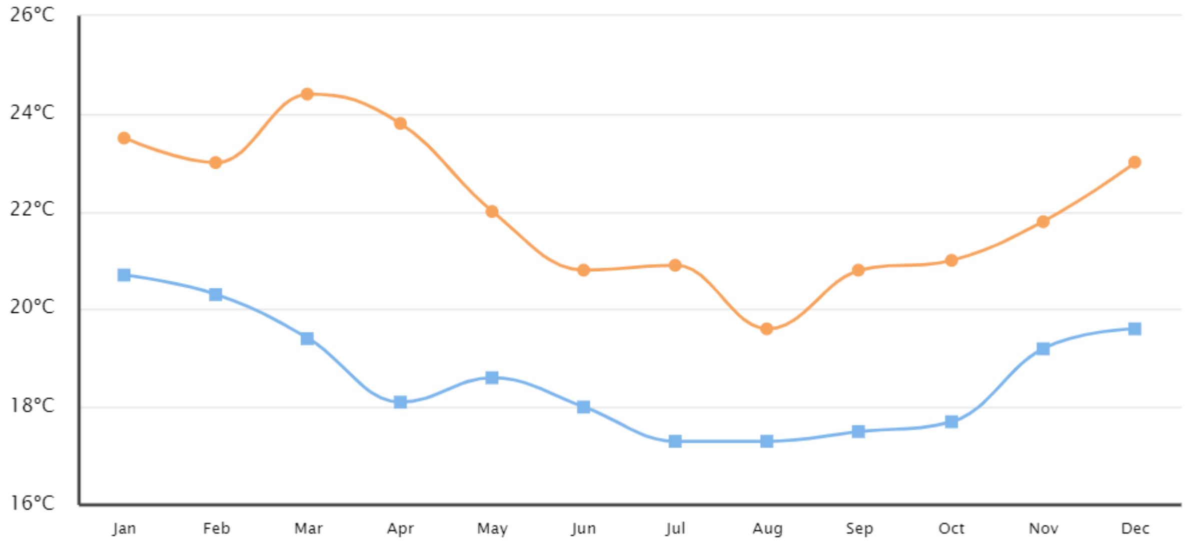


Figure 2-3: The monthly average maximum and minimum ocean temperatures for Port Elizabeth https://www.seatemperature.org/africa/south-africa/port-elizabeth.htm

Table 2-3: The monthly average maximum and minimum ocean temperatures for Port Elizabeth

Month	Average Maximum (°C)	Average Minimum (°C)	Mean Average (°C)
January	20.7	23.5	22.1
February	20.3	23	21.65
March	19.4	24.4	21.9
April	18.1	23.8	20.95
May	18.6	22	20.3
June	18	20.8	19.4
July	17.3	20.9	19.1
August	17.3	19.6	18.45
September	17.5	20.8	19.15
October	17.7	21	19.35
November	19.2	21.8	20.5
December	19.6	23	21.3
Year	**18.6**	**22.1**	**20.3**

2.2.4 Atmospheric Stability

Atmospheric stability is frequently categorised into one of six stability classes. These are briefly described in Table 2-4. Atmospheric stability, in combination with wind speed, is important in determining the extent of a particular hazardous vapour release.

A very stable atmospheric condition, typically at night, would have low wind speeds and produce the greatest endpoint for a dense gas. Conversely, a buoyant gas would have the greatest endpoint distance at high wind speeds.

Table 2-4: Classification scheme for atmospheric stability

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

The atmospheric stability for Ngqura (Coega), as a function of the wind class, was calculated from hourly weather values supplied by the South African Weather Services from the 1st of January 2015 to the 31st of December 2019, as given in
Figure 2-4.

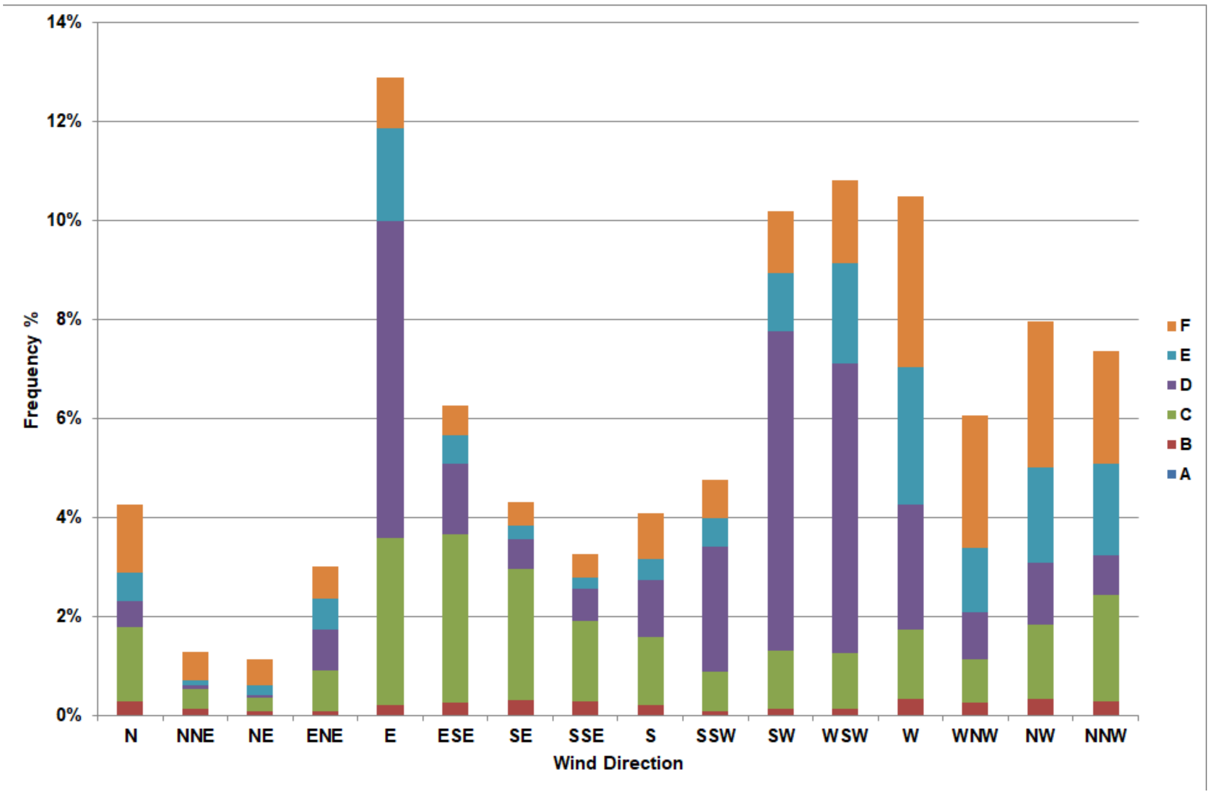


Figure 2-4: Atmospheric stability as a function of wind direction

Calculations for this risk assessment are based on six representative weather classes covering stability conditions of stable, neutral and unstable as well as low and high wind speeds. In terms of Pasquill classes, representative conditions are given in Table 2-5.

Table 2-5: 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 (having speed and direction) and blow preferentially in certain directions, it is mathematically incorrect to give an average wind speed over 360° of wind direction; the result would be incorrect risk calculations.

It would also be incorrect to base risk calculations on one wind category, such as 1.5/F for example. In order to obtain representative risk calculations, hourly weather data for wind speed and direction was analysed over a four-year period and categorised into the six wind classes for day and night conditions and 16 wind directions. The risk was then determined using contributions from each wind class in various wind directions.

The allocation of observations into the six weather classes is summarised in Table 2-6 with the representative weather classes given in Figure 2-5.

Table 2-6: 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" rowspan="2">E 5 m/s</td></tr>
<tr><td>> 6 m/s</td><td colspan="3">D 9 m/s</td></tr>
</table>

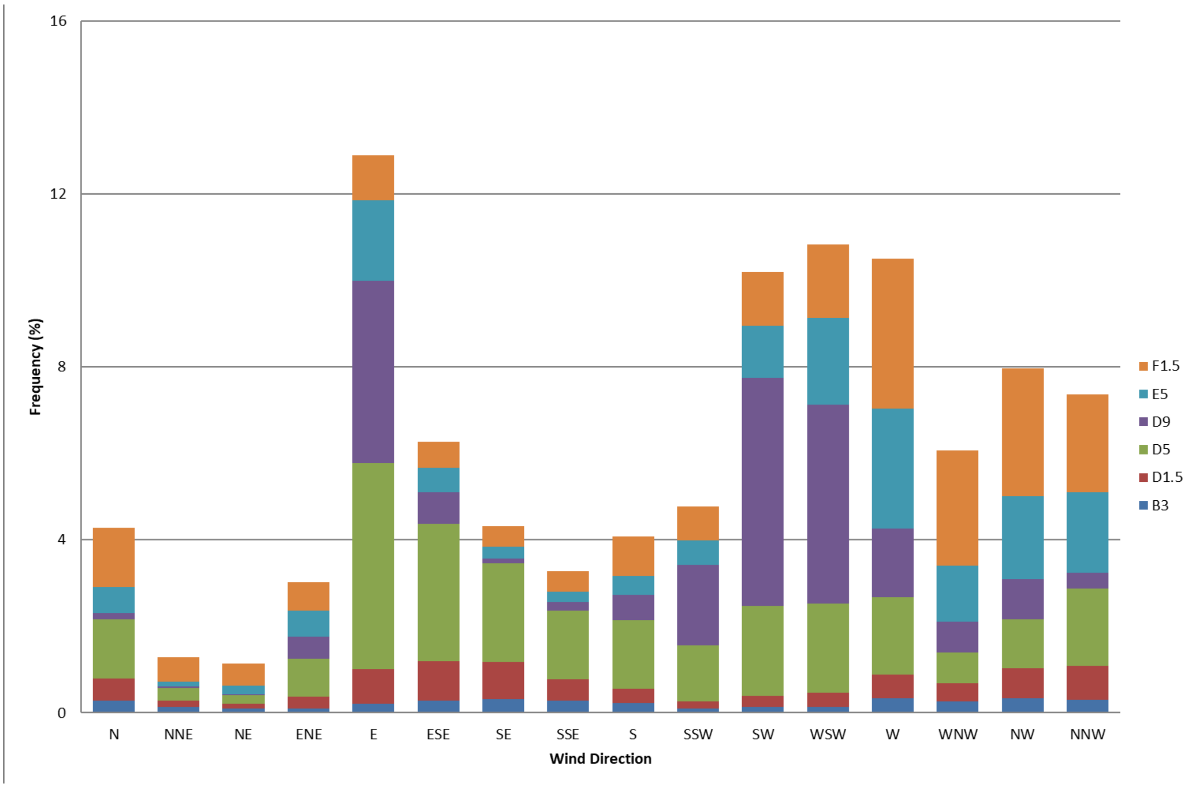


Figure 2-5: Representative weather classes for Ngqura (Coega)

2.2.5 Default Meteorological Values

Default meteorological values used in simulations, based on local conditions, are given in Table 2-7.

Table 2-7: Default meteorological values used in simulations, based on local conditions

Parameter	Default Value (Day)	Default Value (Night)
Ambient temperature (°C)	23	13
Substrate or bund temperature (°C)	18	18
Water temperature (ocean)(°C)	20	20
Air pressure (bar)	1.013	1.013
Humidity (%)	61	82
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 Weather Category D9; 230 m for Weather Category E5; and, 50 m for Weather Category F1.5.

3 PROJECT DESCRIPTION

3.1 Overview

The project is planned over two phases, as shown in the simplified flow diagram shown in Figure 3-1.

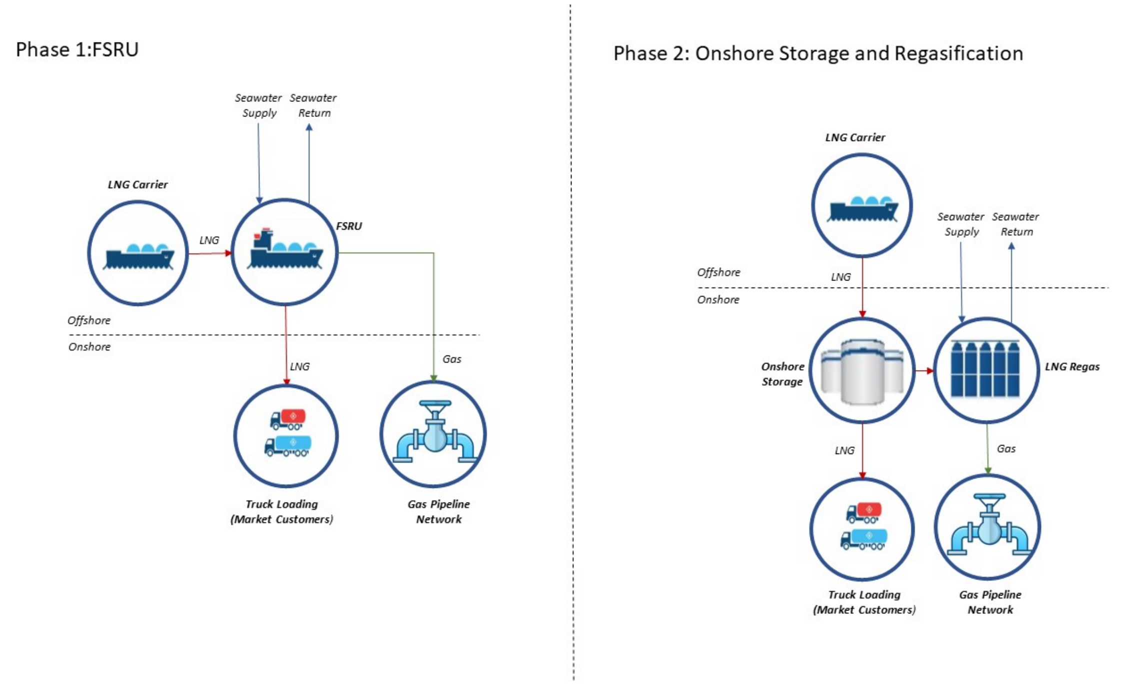


Figure 3-1: Simplified flow diagram of the project process phase

The first phase would involve the importation of LNG from LNG carriers and storing the product in an LNG Floating Storage and Regasification Unit (FSRU), berthed at the Port of Ngqura. Once the offloading of LNG from the carrier, the carrier will then depart the port. The LNG at the FSRU will then store sufficient LNG to continue operations, until the next shipment arrives. There will be up to two FSRUs berthed at the Port of Ngura for operation purposes.

The FSRU will have a regasification unit, which will allow the option to convert the refrigerate LNG, to a gaseous form, by heating the LNG above its boiling point. Once heated, the LNG is no longer a liquid and becomes natural gas (NG) or compressed natural gas (CNG) depending on the storage or transportation pressure. The NG could be sent to the gas hub power stations. A second cryogenic line will transport LNG to the hub for the filling of road tankers. The locality of this phase is shown in Figure 3-2.

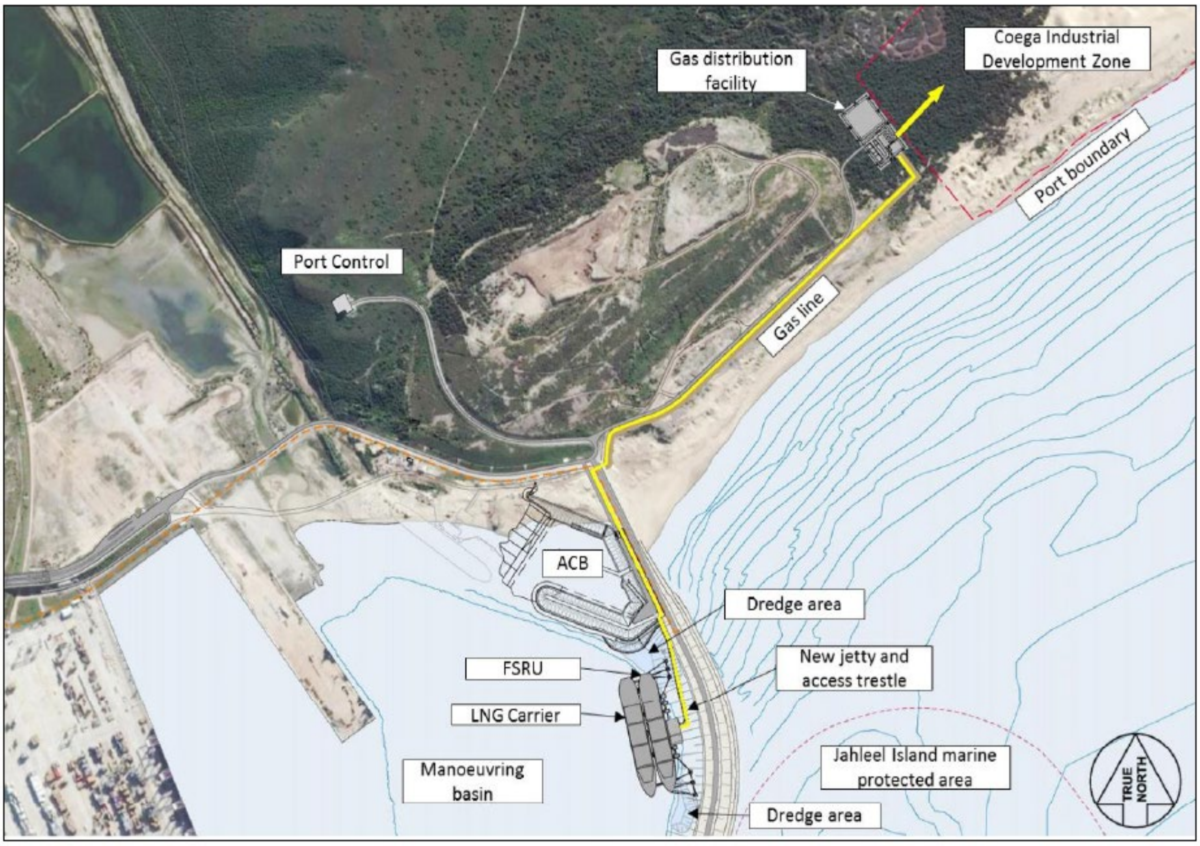


Figure 3-2: Proposed Phase 1 location and pipeline alignment from the LNG carrier to the gas distribution facility (Source: SRK)

The second phase would be the construction of a cryogenic LPG storage on the land, extending the gas distribution facility / gas hub. In this phase, the LNG would be offloaded from the carrier and transported via a cryogenic pipeline to the on-shore storage. The regasification would take place on shore and the NG would be transported via a cryogenic pipeline to the respective power plants and the cryogenic LNG used to fill road tankers. The locality of this phase is shown in Figure 3-3.

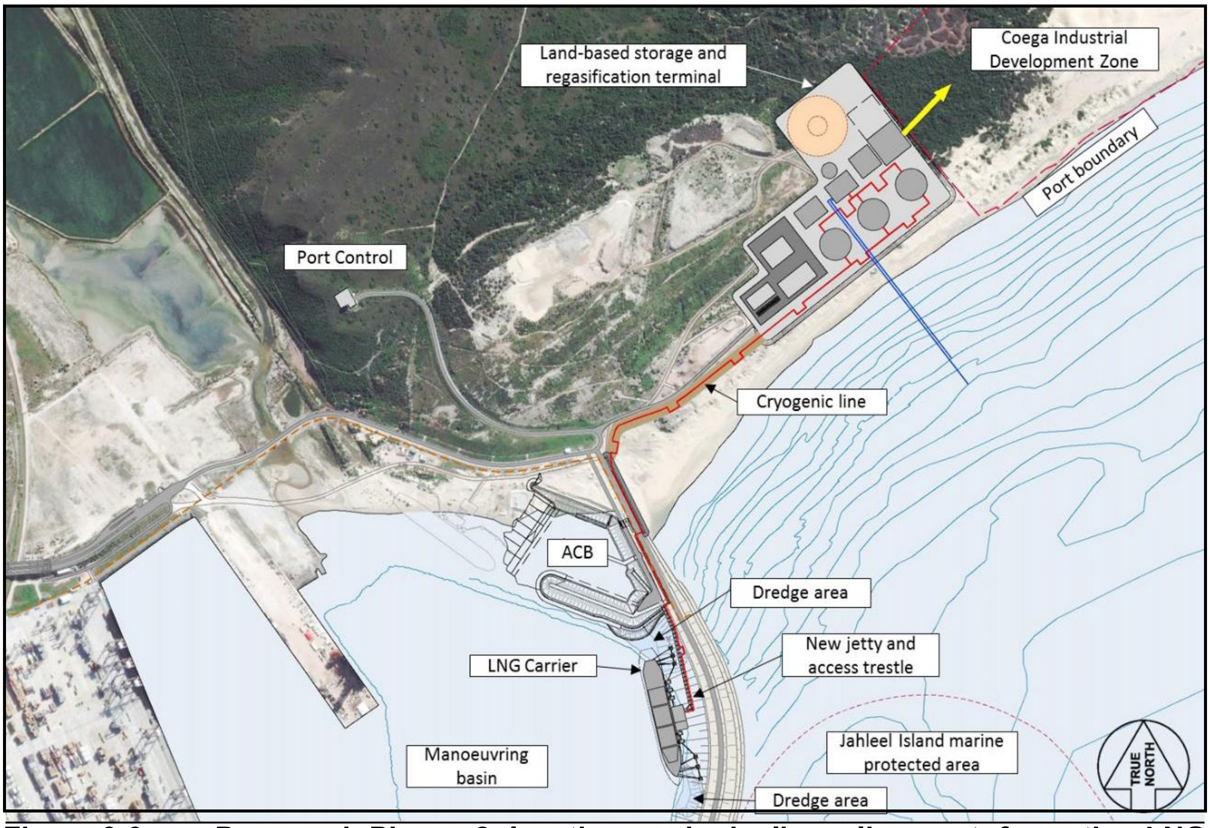


Figure 3-3: Proposed Phase 2 location and pipeline alignment from the LNG carrier to the gas distribution facility (Source: SRK)

These individual processes are discussed in more detail in the sections below, with the object of not only describing the process, but to include the pertinent points and process settings for the modelling the major impact scenarios that could occur.

3.2 Process Description

Natural gas consists mostly of methane, which is a flammable gas at atmospheric conditions. Economical transportation of natural gas would require liquefying the gas so that it would occupy less volume by weight. There are two methods to liquefy natural gas, the first being to compress the gas to a sufficiently high pressure that the gas would remain a liquid and the second way is to reduce the temperature to about -162°C (at mean sea level). The term liquid natural gas (LNG) refers to the liquid state at -162°C. When the LNG is regasified into a vapour state, it is no longer a liquid and referred to a natural gas (NG). When the natural gas is compressed to above its critical pressure of about 46 bar it becomes a supercritical fluid and referred to as compressed natural gas (CNG).

3.2.1 LNG Terminal

An LNG terminal will need to be constructed at the Port of Ngqura to accommodate the LNG transport/storage vessels and offloading operations. The Phase 1 layout, shown in Figure 3-4 with the FSRU permanently moored and the LNG carrier (LNGC) positioned alongside for offloading.

A separate platform of 40 m by 30 m, constructed for the distribution of gas, was allocated for typical plant and equipment required on the LNG platform. The platform will include 2x cryogenic offloading arms with return vapour lines.

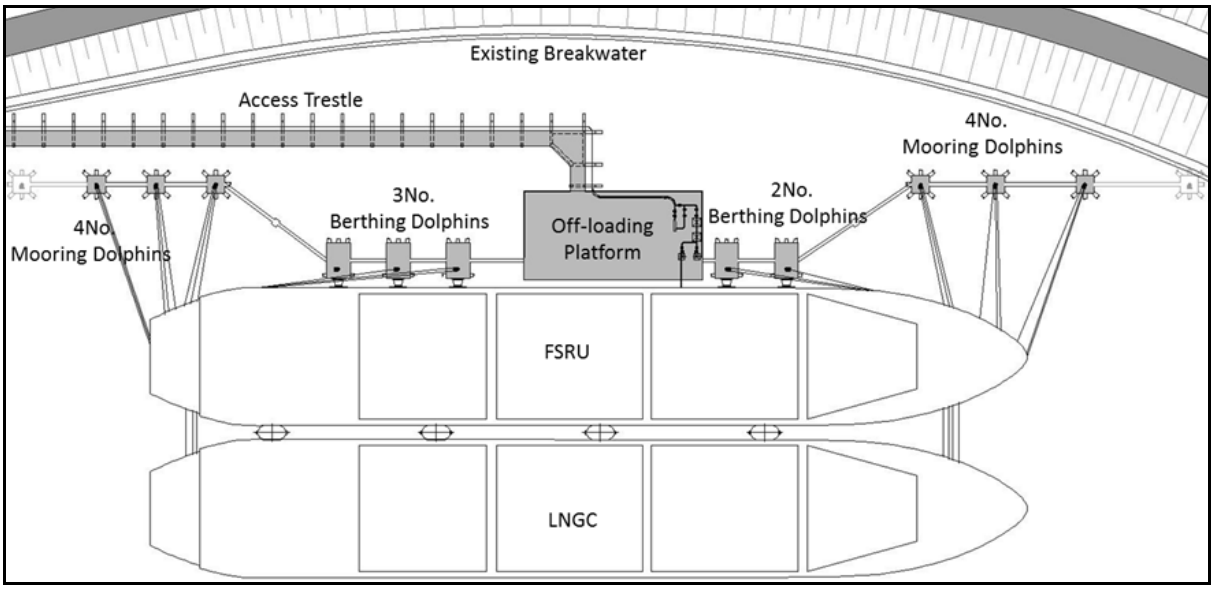


Figure 3-4: Phase 1 – jetty layout –Piled jetty structure (Source: SRK)

3.2.1.1 LNG Carrier (LNGC)

LNG will be delivered to the Port of Ngqura via LNGC vessels of between 140,000 m³ - 170,000 m³ in size. The LNGC would berth alongside the moored FSRU and transfer the LNG across to the FSRU storage tanks.

It is expected that LNG will initially be offloaded via a short cryogenic pipeline from the LNGC to the FSRU. However, once land-based storage is constructed, and the FSRU departs, LNG will then be pumped from the LNGC to onshore storage tanks via cryogenic LNG unloading arms and a cryogenic pipeline. The unloading process takes approximately 12 to 24 hours with the maximum expected ship movements of 52 times per year.

Boil off Gas (BoG) is expected from the storage and transportation of LNG and measures to contain, capture, re-use and recover BoG. BoG are incorporated in the design of the LNGC and cryogenic pipelines. During the unloading of an LNGC, BoG reports back to the LNG tanker's cargo system by a separate vapour return line(s) to ensure that the pressure in both the FSRU or land-based storage tanks and the LNGC storage tanks is maintained within their design operating parameters.

3.2.1.2 Floating Storage and Regasification Unit (FSRU)

The offshore terminal would comprise of a permanently moored floating storage and regasification unit (FSRU). Typically, the FSRU would be a modified LNG carrier build to international LNG standards at the time of construction. It is expected that the FSRU would be similar to the vessel shown in Figure 3-5.

Figure 3-5: Typical LNG carrier

The main components of an FSRU include:

- LNG transfer system (offloading system);
- Storage tanks (in ship);
- Boil-Off Gas handling system;
- LNG pumping system;
- Vaporisation equipment; and,
- Heat source (e.g., seawater).

It is envisaged that up to two FSRU's, each with a storage capacity of 170,000 m³ (i.e., a total storage capacity of 340,000 m³) would be required for the project, although land-based storage is likely to be implemented before the second FSRU becomes a requirement. The FSRU, and potentially the second FSRU, will be berthed permanently at the FSRU terminal.

The FSRU houses onboard LNG regasification facilities for the re-warming of the liquefied gas back to natural gas, via vaporisers. Various re-warming options are available; however, the most likely option will be the extraction of relatively warm seawater and the subsequent discharge of the cooled seawater once it has heated the LNG. The estimated maximum quantity of seawater needed for heating LNG is at 20,840 m³/hour; discharged seawater would be 8º C cooler than the intake water.

The FSRU will also be required to provide an LNG supply for local truck loading operations. Therefore, even though the bulk of the delivery from the FSRU will be via a Natural Gas pipeline, there will be a requirement for a smaller cryogenic pipeline for the FSRU stage of the development. A Liquid LNG Unloading Arm System will be required to provide safe unloading of the liquid LNG from the FSRU for onward conveyance to the LNG Truck Loading Facility. The system will consist of two loading arms, with flow and return lines to enable cooldown and recirculation systems for BoG.

While an FSRU may be economically more viable while the rate of gas consumption is relatively low, it is expected to be more economical to develop land-based storage and regasification once as the demand for Natural Gas increases.

3.2.2 Gas Transmission Pipelines

Two types of gas pipelines are required to transmit both LNG and natural gas from the LNG terminal to the three power plants and the boundary of the Dedisa peaking power plant (if required) and LNG and gas hub in Zone 10. All gas transmission pipelines will be installed underground and will require servitude widths of 20 m for the double cryogenic pipeline (for LNG) and 10 m for the gas pipeline (for natural gas). TNPA's preference for liquid product pipelines to be supported above ground to facilitate leak detection and maintenance is not applicable to gas pipelines, for which the safety benefits of burying the pipeline are decisive.

The pipelines will be approximately 1 km long and will run parallel from the FSRU, supported by a trestle structure running on the inside of the eastern breakwater until it reaches the Admin Craft Basin (ACB), at which point due to space limitations on the inside of the breakwater they will be routed under the breakwater to the seaward side, and run along the coast to the zone 10 power plants as well as to the LNG and gas hub. The pipeline route and road access avoid using the breakwater in accordance with the condition of the environmental Record of Decision stating that no infrastructure may be constructed along the eastern breakwater.

A single natural gas pipeline approximately 6 km long will then run in the services corridor from there to the zone 13 power plant and boundary of the Dedisa power station site. The diameters of the LNG and gas pipelines are currently unknown. Potential interference between the powerlines and gas pipelines (running parallel to each other in the services corridor) resulting from voltages and currents, will be taken into account in the final pipeline design and protection measures against corrosion and induced voltages, including cathodic protection.

3.2.2.1 Natural Gas Pipeline

During the period when the FSRU is in operation (Phase 1 of the LNG terminal), a pipeline will transfer natural gas from the Port to the power plants in Zone 10, and/or connect to the 4 km long gas pipeline from Zone 10 to Zone 13. The gas pipelines and associated servitudes will be accommodated within the services corridor depicted in Figure 3-6. It is expected that the pipeline will be extended up to the existing Dedisa peaking power plant, should this plant convert to gas.

The LNG will feed into the truck loading facility at the gas distribution facility.

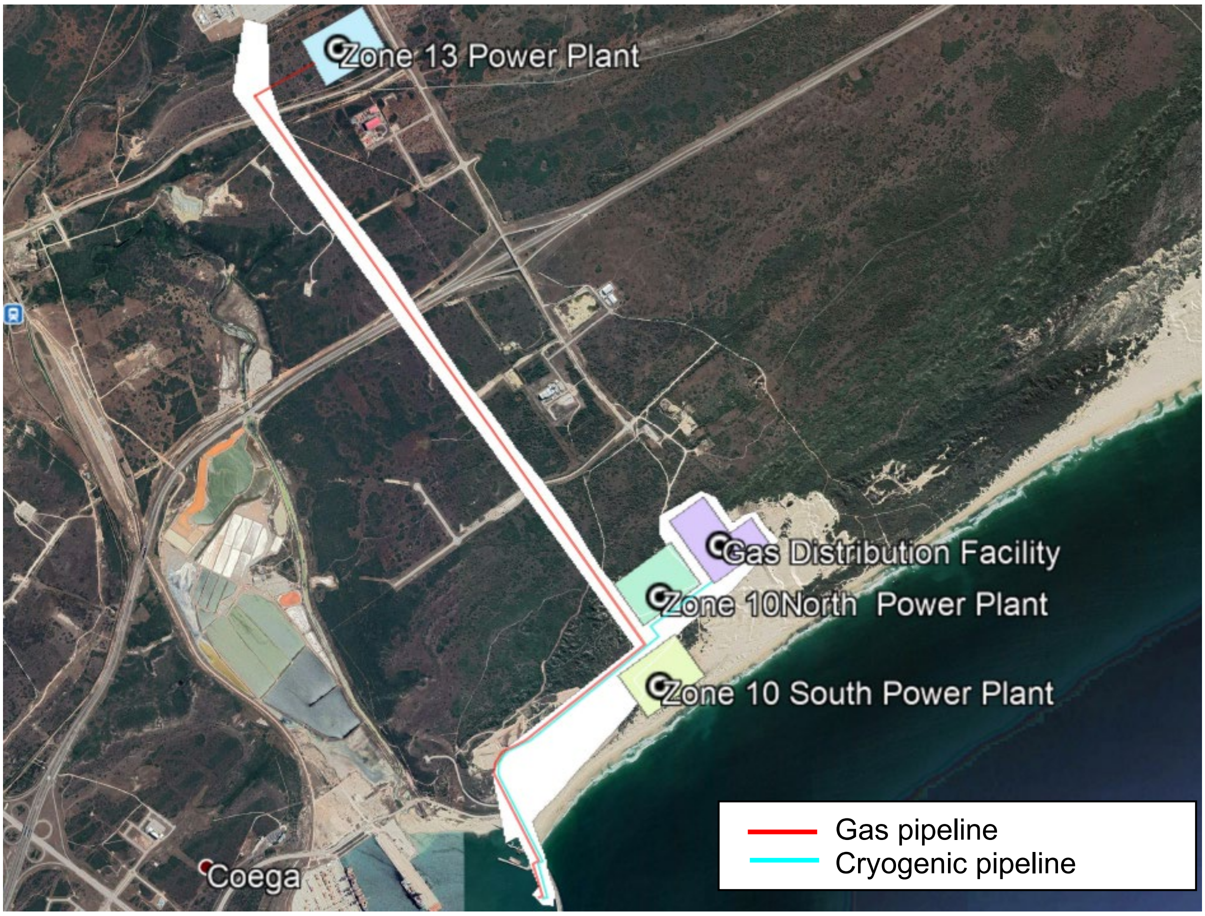


Figure 3-6: Proposed alignment for the gas and cryogenic pipelines from the FSRU the power plants and gas distribution centre

3.2.2.2 Cryogenic Pipelines

LNG cryogenic pipelines will be installed to accommodate LNG distribution to end users (via the truck distribution centre located in the LNG and gas hub in Zone 10). The pipeline will convey the LNG from the FSRU via the trestle and along the coastline, following the alignment of the gas pipeline, to the proposed LNG and gas distribution facility, and will include a return pipeline (i.e., a double cryogenic pipeline, with a combined servitude of 20 m is proposed).

Phase 2 of the proposed LNG terminal development will entail onshore storage and regasification. This will include cryogenic pipelines to feed LNG from the LNG carrier to the land-based storage and regasification terminal located at the LNG and gas hub in Zone 10. The cryogenic pipelines will be routed under the main breakwater as there is insufficient space between the ACB and breakwater to accommodate the above-ground cryogenic pipelines (See Figure 3-7).

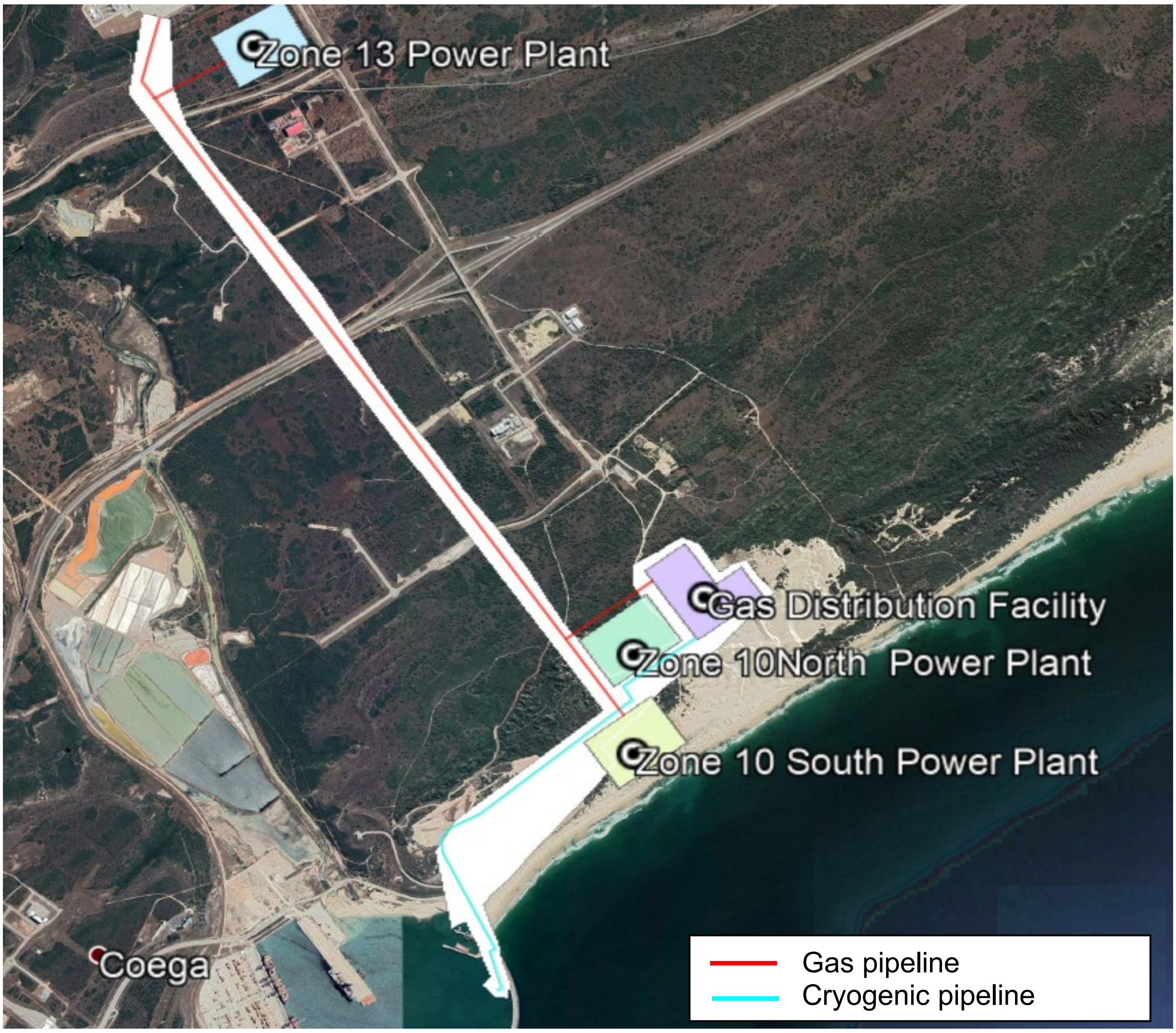


Figure 3-7: Proposed alignment for the gas and cryogenic pipelines from the FSRU the power plants and gas distribution centre

3.2.3 Gas Distribution Facility / Gas Hub

The LNG and gas hub will be located adjacent to the Zone 10 North power plant as indicated on Figure 3-8 which include facilities for land-based LNG storage and regasification, as well as the truck distribution centre (for third party supply of LNG and gas). The hub will occupy a footprint of up to 23.1 ha, and will be fenced with an access-controlled entrance point.

Facilities within the storage and regasification area include admin offices, a utility station, a control room, a maintenance and repairs workshop, a store, a cold vent system, a metering package and pig launcher. The truck distribution centre will include a weighbridge, control cabin and loading facilities. A conceptual drawing of what the layout of the facility may look like is provided in Figure 3-8. The hub will be connected to fire water pipelines (running from the LNG terminal in the port), gas and LNG transmission pipelines.

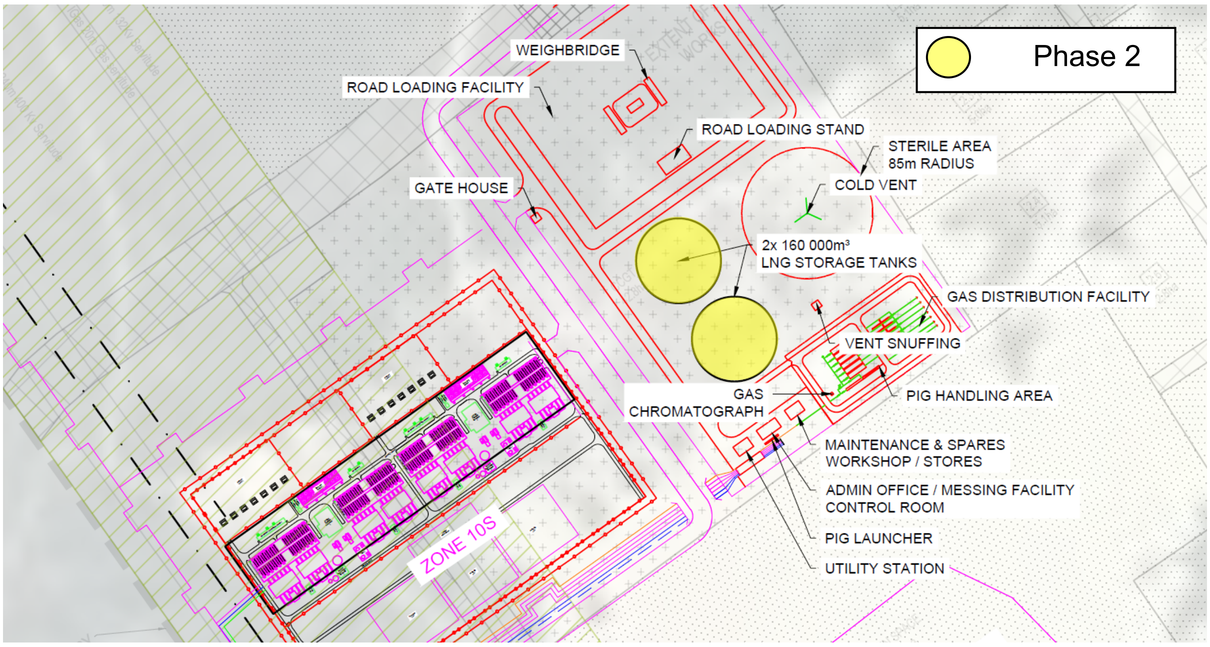


Figure 3-8: Conceptual layout of infrastructure that the gas distribution facility / gas hub

3.2.4 LNG storage

It is proposed that during Phase 2 of the gas infrastructure development, the FSRU will no longer be the most feasible option and land-based storage and regasification will become economically more feasible. The cryogenic pipelines (already constructed in Phase 1) will feed LNG directly from the LNG terminal to a new land-based storage and regasification terminal at the LNG and gas hub. LNG storage tanks are designed to withstand cold temperatures, maintain the liquid at low temperature, and minimise the amount of evaporation. The BoG is usually captured and recondensed to be sent to the vaporiser with LNG or compressed gas and sent via the return cryogenic pipeline back to the storage and regasification unit.

It is estimated that two LNG Storage tanks of 70,000 m³ each will be required for the FSRU and two tanks of 160,000 m³ each for onshore regasification during Phase 2 (i.e., total LNG storage of 320,000 m³ to 340,000 m³) will be required (Carnegie Energie, 2019). No storage of natural gas is proposed.

The storage facility will require a venting system as protection against the risk of overpressure due to “roll-over” in the LNG tank. LNG “rollover” refers to the rapid release of LNG vapours from a storage tank, resulting from stratification.

3.2.5 LNG Regasification

The main component in the regasification process is the vaporiser, i.e. heat exchangers used to return the LNG to its regular vapour phase. Due to the proximity of the sea, it is expected that the technically preferred vaporisers would be Open Rack Vaporisers (ORV). ORVs take seawater and stream it over the vertical tubes of the vaporisers in order to warm up the LNG. This is the most common type and generally is the preferred choice where warm seawater is available. The estimated maximum quantity of seawater needed for heating LNG is 20,840 m³/hour, and discharged seawater would be 8ºC cooler than the intake water).

Infrastructure for the intake and discharge of seawater for heating purposes is excluded from the scope of this EIA process and will be addressed by the CDC’s Marine Pipeline Servitude EIA process that is currently underway. The seawater abstraction point is anticipated to be within the port. Cooling water intake and discharge pipelines will be 2.5 m in diameter and run underground, parallel to the coast on the seaward side of the gas pipelines, connecting to the zone 10 power plants and to the LNG and gas hub (for supply of heating water for regasification).

3.2.6 Cold vent system

The regasification and storage facility (both onshore and offshore) will have its own independent overpressure protection and venting systems, as well as fire and gas, and depressurisation regimes. The design of the project is expected to be in accordance with a philosophy of minimum venting in order to protect the environment without compromising safety. During normal operation, there will be no flow of vapour from the facilities into the vent system.

Relief and vent streams from the FSRU are expected to be handled by the FSRU. Operational and minor upsets in the LNG Truck Loading Facility are also assumed to return to the FSRU (or onshore regasification unit once this is operational) through the cryogenic recirculation pipeline.

The vent system will need to be sized to handle vapour resulting from depressurisation of the gas pipeline between the jetty and the Emergency Shut Down Valve at the gas distribution facility, and any other coincident relief scenarios.

It is anticipated that there will be a requirement to depressurise the above ground section of the gas pipeline between the FSRU and the underground section of pipeline. It is not anticipated that it will be necessary to blow down the underground section of gas pipeline.
An emergency Cold Vent system will be required to provide safe release of gas and depressurisation of the gas containing facilities up to the Emergency Shut Down Valve at the Gas Distribution Facility, in the event of an emergency upset or start-up/run-down conditions.

The Cold Vent System is expected to terminate in a pipe vent supported by a structural steel stack of a height and location designed to ensure suitable dispersion of the gas. The Cold Vent System is expected to be provided with a Snuffing Package for manual use in the event of ignition.

3.2.7 Gas Distribution

The gas exported from the regasification unit will be transported to a gas distribution centre at the LNG and gas hub. The facility will have its own access point with a gate, and will include facilities for gas chromatography as well as pig handling and receiving.

Gas will be regulated at the facility to meet the export gas pressure and flow requirements based on the client's specific purposes. It is envisaged that the distribution facility will serve the power plants and third-party users, including a truck loading facility. The gas may also be conditioned to correct for Wobbe Index using LPG and/or Nitrogen.

Each individual customer stream will be regulated to provide customer-specific pressure and flow rate requirements, and to allow metering of the gas. Once the gas passes the custody point, the gas is considered sold, and all facilities downstream of that point would be the responsibility of the customer.

Facilities for online operational pigging are included at each end to allow for pipeline inspection and integrity management. The receiving facilities at the distribution centre include a gas filter to allow any impurities in the pipeline after construction to be removed prior to export to clients. Long term use of the gas filter may not be required, depending on the pipeline and upstream facility cleanliness.

In addition to the above-mentioned items, the gas distribution facilities typically include:

- Emergency shutdown valves to automatically isolate the pipeline on the activation of a shutdown event;
- Valves on each customer stream to allow for the isolation of the particular stream for performance of maintenance on any of the equipment;
- Control room for local operation of the system;
- A cold vent to allow for de-pressurisation of any part of the facility as required in an emergency or during routine maintenance;
- Gas conditioning, which typically includes a gas mixing vessel and LPG and / or Nitrogen supply; and
- Firefighting facilities for emergency response in the event of fire.

3.2.8 Truck loading facility

A Truck Loading Facility will be provided within the LNG and gas hub for third party offtake. This will be complete with recirculation systems for BoG and LNG. The Truck Loading Facility will typically comprise a weighbridge and associated loading arms. Initially it is assumed that parallel loading of two road tankers should be provided for. The estimated offtake of LNG is approximately of 787 tpd, providing offtake by 40 x 20-ton LNG trucks per day.

3.3 Summary of Bulk Materials to be Stored on Site

A summary of bulk materials that can give hazardous effects that are to be stored on site is given in Table 3-1.

Table 3-1: Summary of hazardous components to be stored on site

No.	Component	CAS No.	Inventory	Comment
1	LNG	74-82-8	170 000 m^3	FSRU - Phase 1
2	LNG	74-82-8	2 x 160 000 m^3	Storage - Phase 2

4 METHODOLOGY

4.1 Methodology Standards

The methodology for this study for the study is generally based on the South African SANS 1461 (2018) for scenario definitions, failure rates, risk criteria and calculation assumptions. The SANS 1461 (2018) is based on the Dutch legislation RIVM (2009) for of process equipment, while the methodology for underground pipeline is based on IGEM/TD/2 and PD 8010-3, which is the requirement of the United Kingdom. The methodology of the underground pipelines and process plant differ slightly, taking into account the differences between the standards different outflow methodologies and failure rates.

4.2 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. 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 considerations are taken into account:

- Chemical identities;
- Location of on-site installations that use, produce, process, transport or store hazardous components;
- Type and design of containers, vessels or pipelines;
- Quantity of material that could be involved in an airborne release;
- Nature of the hazard most likely to accompany hazardous materials spills or releases, e.g., airborne toxic vapours or mists, fires or explosions, large quantities to be stored and certain handling conditions of processed components.

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.

4.2.1 Notifiable Substances

The General Machinery Regulation 8 and its Schedule A on notifiable substances requires any employer who has a substance equal to or exceeding the quantity listed in the regulation to notify the divisional director. A site is classified as a Major Hazard Installation if it contains one or more notifiable substances or if the off-site risk is sufficiently high. The latter can only be determined from a quantitative risk assessment.

Methane (compressed) is listed as a notifiable substance at a threshold value of 15 t. The schedule does not specifically mention LNG. Furthermore, the storage of LNG would be in the liquid state and not compressed. To this end LNG would not be classified as a notifiable substance.

However, if the design changes so that more than 15 t of CNG would be contained in a single container, the CNG would be classified as a notifiable substance and the facility would automatically be classified as a Major Hazard Installation.

4.2.2 Substance Hazards

All components on site were assessed for potential hazards according to the criteria discussed in this section.

4.2.2.1 Chemical Properties

A short description of bulk hazardous components to be stored on, produced at or delivered to site is given in the following subsections. The material safety data sheets (MSDSs) of the respective materials are attached in Appendix E.

- **Natural Gas**

Natural gas consists mainly of methane (92.6 mol. %) with minor concentrations of ethane, propane, nitrogen of higher chained alkanes.

Given the flammable and potentially explosive nature of natural gas, fires and vapour cloud explosions represent the primary hazards associated with the 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) of natural gas is 5% v/v (meaning 5% gas to 95% air, measured by volume) and the upper explosive limit (UEL) is 15% v/v. In unconfined atmospheric conditions the likelihood of an explosion is expected to be small.

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

Natural gas is nontoxic and is to be considered as an asphyxiant only. Chronic and long-term effects are not significant and are not listed.

Natural gas is a gas at atmospheric temperatures and pressures. Economical transportation of natural gas would require either liquefying the gas so that would occupy less volume per weight. The liquefied natural gas (LNG) has a low temperature of -162°C (at atmospheric pressure). Appendix E gives the expected composition of the LNG.

Another economical form of transportation, particularly in pipelines, is to compress the gas to reduce the density. The critical pressure of methane is 46 bar and thus compressed natural gas (CNG) above the critical pressure would be a supercritical gas having a density similar to that of the liquid form.

4.2.2.2 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.

No bulk materials to be stored on, produced at or delivered to site are considered extremely corrosive.

4.2.2.3 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.

All components to be stored on, produced at or delivered to site are considered thermally stable in atmospheric conditions. The reaction with air is covered under the subsection dealing with ignition probabilities.

4.2.2.4 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 4-1. These components have been analysed for fire and explosion risks.

Table 4-1: 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	Flammable gas	Flammable gas	5	15

4.2.2.5 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 subsequently 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 material in the air and the exposure duration.

No bulk components to be stored on, produced at or delivered to site are considered acutely toxic. Cold natural gas may result in asphyxiation from a release. However, the impacts from fires and explosions would be more severe, as covered in the previous section.

4.2.3 Physical Properties

For this study, LNG and CNG were modelled as a pure component, as given in Table 4-2. The physical properties used in the simulations were based on the DIPPR[1] data base, preinstalled in the software.

Table 4-2: Representative components

Component	Modelled as
LNG (CNG)	Methane

1 Design Institute for Physical Properties

4.2.4 Excluded from the Study

This study concentrated on the loss of containment of natural gas, refrigerated and at elevated pressure from the LNG carrier to the end destination. Excluded from this study are the following:

- LNG carrier accidents in the port;
- Loss of containment of marine oil from the LNG carrier into the port;
- Incidents aboard the LNG carrier;
- Cold vent, as this has not been properly specified.

4.3 Physical and Consequence Modelling

In order to establish which impacts, 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 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.

4.3.1 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.

4.3.1.1 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 Table 4-3.

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

Table 4-3: 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:

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

4.3.1.2 Bund and Pool Fires

Pool fires, either tank or bund fires, consist of large volumes of a flammable liquid component burning in an open space at atmospheric pressure.

The flammable component will be consumed at the burning rate, depending on factors including prevailing winds. During combustion heat will be released in the form of thermal radiation. Temperatures close to the flame centre will be high but will reduce rapidly to tolerable temperatures over a relatively short distance. Any building or persons close to the fire or within the intolerable zone will experience burn damage with severity depending on the distance from the fire and time exposed to the heat of the fire.

In the event of a pool fire, the flames will tilt according to the wind speed and direction. The flame length and tilt angle affect the distance of thermal radiation generated.

4.3.1.3 Jet Fires

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

In 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.

4.3.1.4 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.

4.3.2 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:

- Blast damage;
- Thermal damage;
- Missile damage;
- Ground tremors;
- Crater formation;
- 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 4-4 and Table 4-5 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:

- 0.03 bar overpressure, corresponding to the critical overpressure causing windows to break;
- 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;
- 0.3 bar overpressure, corresponding to structures being severely damaged and 100% fatality for unprotected people in the open;
- 0.7 bar overpressure, corresponding to an almost entire destruction of buildings.

Table 4-4: 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.
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 4-5: 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)
Pine 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								MQ						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				

4.3.2.1 Vapour Cloud Explosions (VCEs)

The release of a flammable component 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.

4.3.2.2 Boiling Liquid Expanding Vapour Explosions (BLEVEs)

A boiling liquid expanding vapour explosion (BLEVE) can occur when a flame impinges on a pressure cylinder, particularly in the vapour space region where cooling by evaporation of the contained material does not occur; the cylinder shell would weaken and rupture with a total loss of the contents, and the issuing mass of material would burn as a massive fireball.

The major consequences of a BLEVE are \ intense thermal radiation from the fireball, a blast wave and propelled fragments from the shattered vessel. These fragments may be projected to considerable distances. Analyses of the travel range of fragment missiles from a number of BLEVEs suggest that the majority land within 700 m from the incident. A blast wave from a BLEVE is fairly localised but can cause significant damage to immediate equipment.

A BLEVE occurs sometime after the vessel has been engulfed in flames. Should an incident occur that could result in a BLEVE, people should be evacuated to beyond the 1% fatality line.

4.4 Risk Analysis

4.4.1 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 4-6.

Table 4-6: 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.

4.4.2 Predicted Risk

Physical and consequence modelling addresses the impact of a release of a hazardous component without taking into account 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.

4.4.2.1 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.

4.4.2.2 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, respectively, in Table 4-7 and Table 4-8.

Table 4-7: Failure frequencies for atmospheric vessels

Event	Leak Frequency (per item per year)
Small leaks	$1x10^{-4}$
Severe leaks	$3x10^{-5}$
Catastrophic failure	$5x10^{-6}$

Table 4-8: Failure frequencies for pressure vessels

Event	Failure Frequency (per item per year)
Small leaks	$1x10^{-5}$
Severe leaks	$5x10^{-7}$
Catastrophic failure	$5x10^{-7}$

4.4.2.3 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 given in Table 4-9 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.

Table 4-9: Failure frequencies for process pipes

Description	Frequencies of Loss of Containment for Process Pipes (per meter per year)	
	Full Bore Rupture	Leak
Nominal diameter < 75 mm	$1x10^{-6}$	$5x10^{-6}$
75 mm < nominal diameter < 150 mm	$3x10^{-7}$	$2x10^{-6}$
Nominal diameter > 150 mm	$1x10^{-7}$	$5x10^{-7}$

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 Table 4-10, and those for underground pipes are given in Table 4-11.

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.

Table 4-10: 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	$1x10^{-6}$	$3x10^{-7}$	$1x10^{-7}$
Leak with an effective diameter of 10% of the nominal diameter, up to a maximum of 50 mm	$5x10^{-6}$	$2x10^{-6}$	$5x10^{-7}$

Table 4-11: Failure frequencies for underground transport pipelines

Description	Frequency (per meter per annum)		
	Pipeline in Pipe Lane[1]	Pipeline Complies with NEN 3650	Other Pipelines
Full bore rupture	$7x10^{-9}$	$1.525x10^{-7}$	$5x10^{-7}$
Leak with an effective diameter of 20 mm	$6.3x10^{-8}$	$4.575x10^{-7}$	$1.5x10^{-6}$

4.4.2.4 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 (sealless 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 Table 4-12 and Table 4-13.

Table 4-12: Failure frequency for centrifugal pumps and compressors

Event	Canned (No Gasket) Frequency (per annum)	Gasket Frequency (per annum)
Catastrophic failure	$1.0x10^{-5}$	$1.0x10^{-4}$
Leak (10% diameter)	$5.0x10^{-5}$	$4.4x10^{-3}$

Table 4-13: Failure frequency for reciprocating pumps and compressors

Event	Frequency (per annum)
Catastrophic failure	$1.0x10^{-4}$
Leak (10% diameter)	$4.4x10^{-3}$

1 A 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.

4.4.2.5 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 Table 4-14.

Table 4-14: Failure frequencies for loading and offloading arms and hoses

Event	Frequency (per hour)	
	Loading and Offloading Arms	Loading and Offloading Hoses
Rupture	$3x10^{-8}$	$4x10^{-6}$
Leak with effective diameter at 10% of nominal diameter to max. 50 mm	$3x10^{-7}$	$4x10^{-5}$

4.4.2.6 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 Table 4-15 and Table 4-16.

Table 4-15: Failure frequencies for road tankers with an atmospheric tank

Event	Frequency (per annum)
Instantaneous release of the entire contents	$1x10^{-5}$
Release of contents from the largest connection	$5x10^{-7}$

Table 4-16: Failure frequencies for road tankers with a pressurised tank

Event	Frequency (per annum)
Instantaneous release of the entire contents	$1x10^{-7}$
Release of contents from the largest connection	$5x10^{-7}$

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.

4.4.2.7 LNG Tanker Offloading

There are no scenarios for the intrinsic failure of a ship. Loading scenarios are dominant compared to intrinsic failure (RIVM 2009).

The only scenarios that are relevant in addition to loading are external damage as a result of ship collisions. These are very much determined by the local situation. In the case that a ship is located in a (small) port outside the transport routes, the probability of a collision that leads to an outflow is so small that it does not need to be taken into consideration.

In other cases, the basic failure frequency for accidents has to be determined based upon the specific route section. This is best obtained from a marine risk assessment.
In the case where the LNG carrier, would be berthed at the jetty within the Port of Ngqura, risk analysis would be completed using a general basic failure frequency for accidents. This is equal to:

$$6.7 \times 10^{-11} \times T \times t \times N$$

Where T is the total number of ships per annum on the transport route or in the port
t is the average loading time for each ship (in hours)
N is the number of loading operations per annum.

Assuming one LNG ship is offloading for the full year and an unprecedented number of ships would be 1000, the failure rate would be equal to 7×10^{-7} releases per annum.

4.4.2.8 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:

- Human failure during design, construction and modification of the facility;
- Human failure during operation and maintenance;
- 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 Table 4-17.

Table 4-17: 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}

4.4.2.9 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 Table 4-18 (along with classification of flammable substances in Table 4-19). 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.

Table 4-18: 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[1]
Category 3 Category 4	All flow rates	All quantities	0

Table 4-19: 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.

1 This 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.

Note: Methane is classified as an unreactive gas. As such, the pipeline probability was equal to the typical overall probabilities for Natural Gas, used by HSE (IGEM/TD/2 (2012)), as follows:

- immediate ignition resulting in a fireball followed by jet fire: 0.25;
- delayed ignition resulting in a jet fire: 0.1875;
- no ignition: 0.5625.

4.4.3 Risk Calculations

4.4.3.1 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.

4.4.3.2 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:

- Whether a risk is so high that something must be done about it;
- Whether the risk is or has been made so small that no further precautions are necessary;
- 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 4-1.

ALARP stands for 'as low as reasonably practicable'. As used in the UK, it is the region between that which is intolerable, at $1x10^{-4}$ per year, and that which is broadly acceptable, at $1x10^{-6}$ per year. A further lower level of risk, at $3x10^{-7}$ per year, is applied to either vulnerable or very large populations for land-use planning.

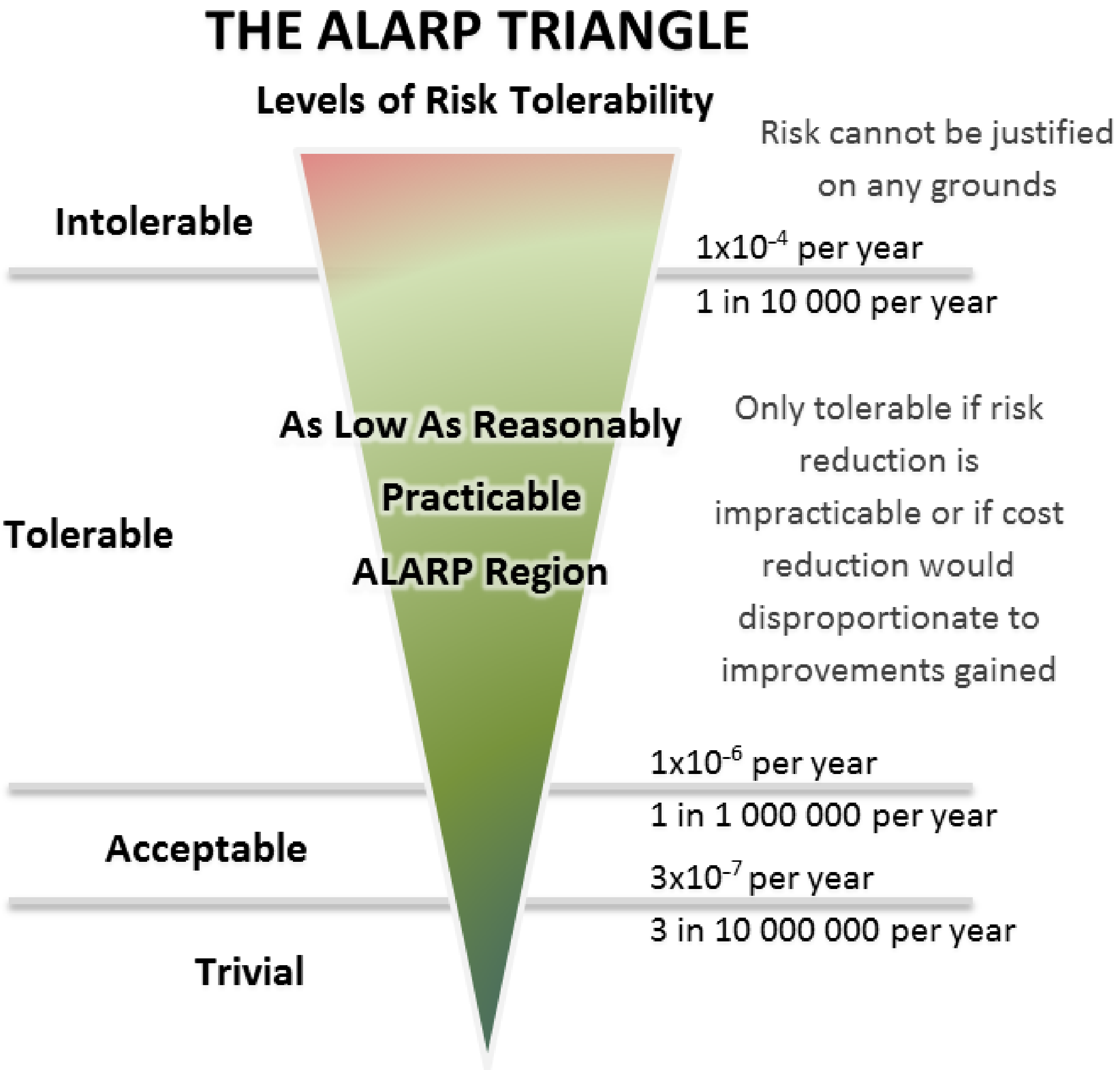


Figure 4-1: UK HSE decision-making framework

It should be emphasised that the risks considered acceptable to employees are different to those considered acceptable to the public. This is due to the fact that employees 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:

“ *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:*

- *To spend £1m to prevent five staff members suffering bruised knees is obviously grossly disproportionate; but,*
- *To spend £1m to prevent a major explosion capable of killing 150 people is obviously proportionate.*

Proving ALARP means that if the risks are lower than $1x10^{-4}$ fatalities per person per year, it can be demonstrated that there would be no more benefit from further mitigation, sometimes using cost benefit analysis. “

4.4.3.3 Land Planning

There are no legislative land-planning guidelines in South Africa and 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 to the ALARP approach (HSE 2011).

The three zones are defined as follows:

- The inner zone is enclosed by the risk of $1x10^{-5}$ fatalities per person per year isopleth;
- The middle zone is enclosed by the risk of $1x10^{-5}$ fatalities per person per year and the risk of $1x10^{-6}$ fatalities per person per year isopleths;
- The outer zone is enclosed by the risk $1x10^{-6}$ fatalities per person per year and the risk of $3x10^{-7}$ fatalities per person per year isopleths.

The risks decrease from the inner zone to the outer zone as shown in Figure 4-2 and Figure 4-3.

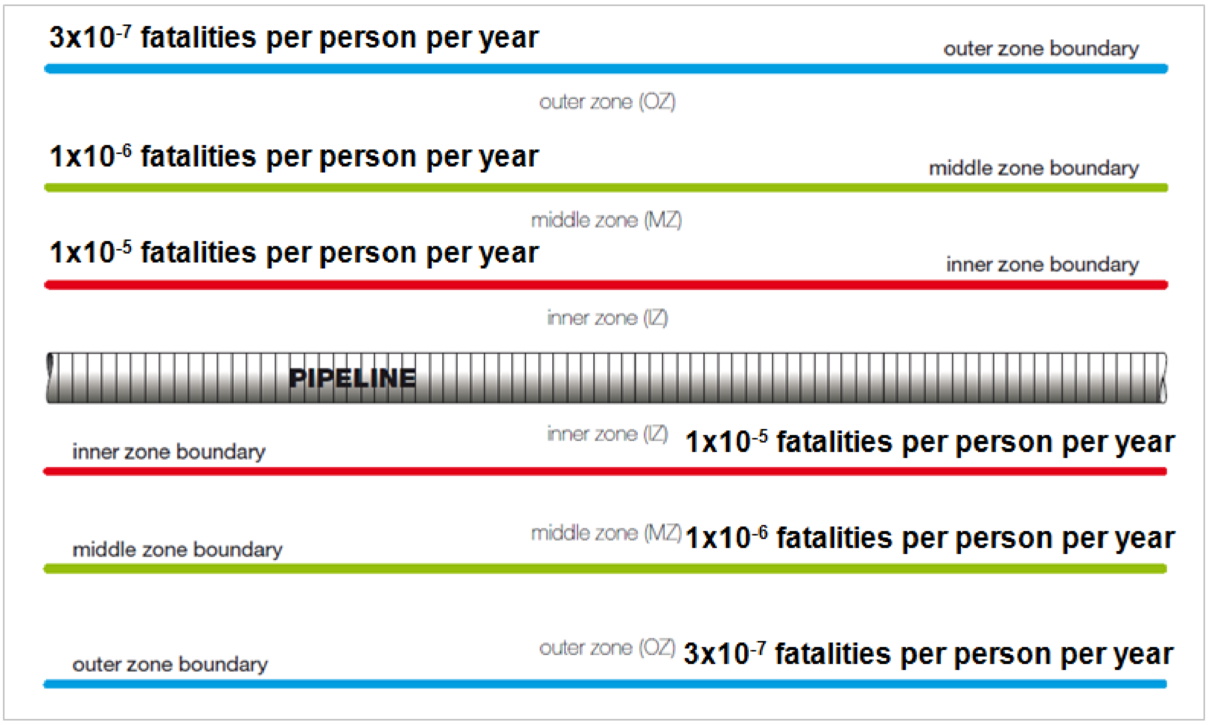


Figure 4-2: Town-planning zones for pipelines

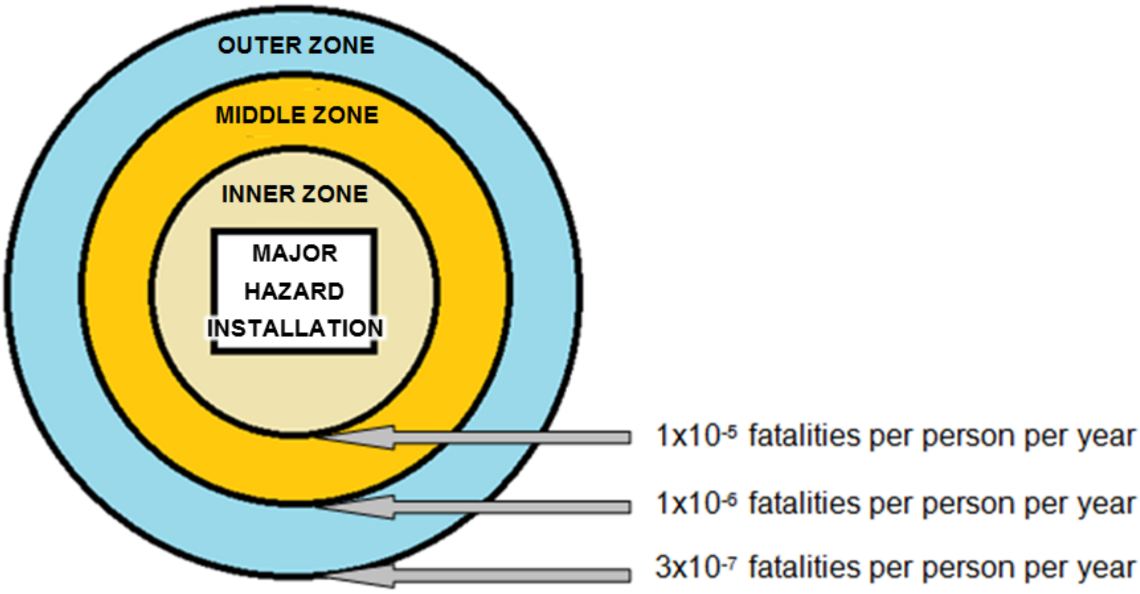


Figure 4-3: Town-planning zones

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 4-20. There are no land-planning restrictions beyond the outer zone.

Table 4-20: 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:

- Level 1 is based on workers who have been advised of the hazards and are trained accordingly;
- Level 2 is based on the general public at home and involved in normal activities;
- 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);
- Level 4 is based on large examples of Level 2 and of Level 3.

Refer to Appendix D for detailed planning advice for developments near hazardous installations (PADHI) tables. 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.

4.5 Quantitative Risk Assessment (QRA) Scenarios

4.5.1 Methodology

SANS 1461 (2018) is based on RIVM (2009) for process plants. The latter standards describe the minimum scenarios to be included in the assessment, as well as the assumptions to be used. As full compliance of SANS 1461 (2018) cannot be achieved within the NEMA legislative framework, general compliance of the aforementioned standards at this stage would be applicable and briefly described in the sections below. This general compliance assessment constitutes a quantitative risk assessment (QRA).

The evaluation of the acceptability of the risks is done in accordance with SANS 1461 (2018) the Health and Safety Executive (HSE; UK) ALARP criteria, which clearly covers land use, based on the determined risks.

The QRA process 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 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), taking into account all generic failure rates, initiating events (such as ignition), meteorological conditions and lethality.

Scenarios included in this QRA have impacts external to the establishment. 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.

4.5.2 Scenario Selection

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.

4.5.2.1 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 of Figure 4-4,as per PD 8010-3:2009 (2009) for LNG pipelines). 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.

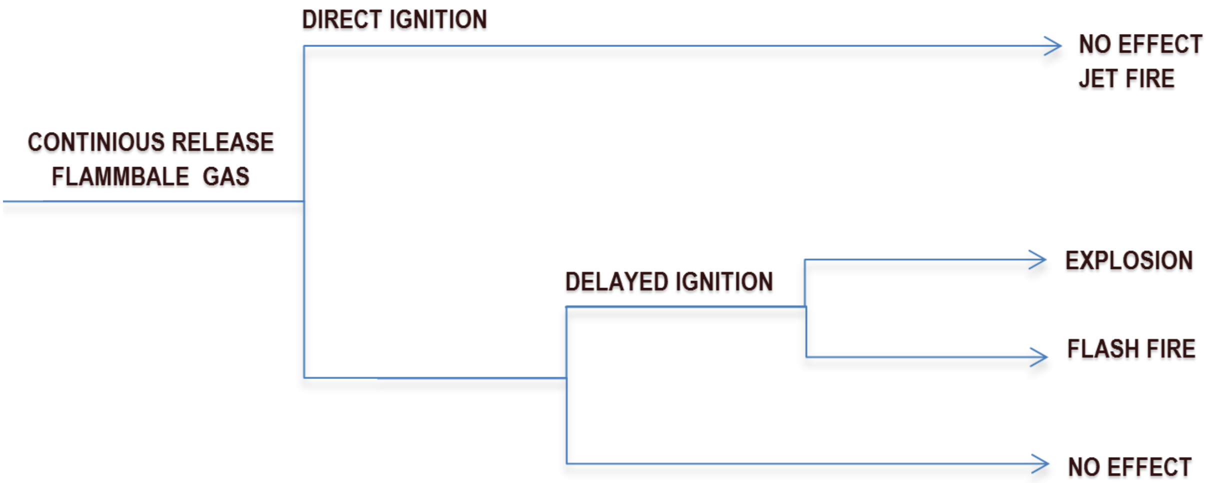


Figure 4-4: Event tree for a continuous release of a flammable gas

4.5.2.2 Continuous Release of a Flammable Liquid

The continuous loss of containment of a flammable liquid could result in the consequences given in the event tree of Figure 4-5. 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.

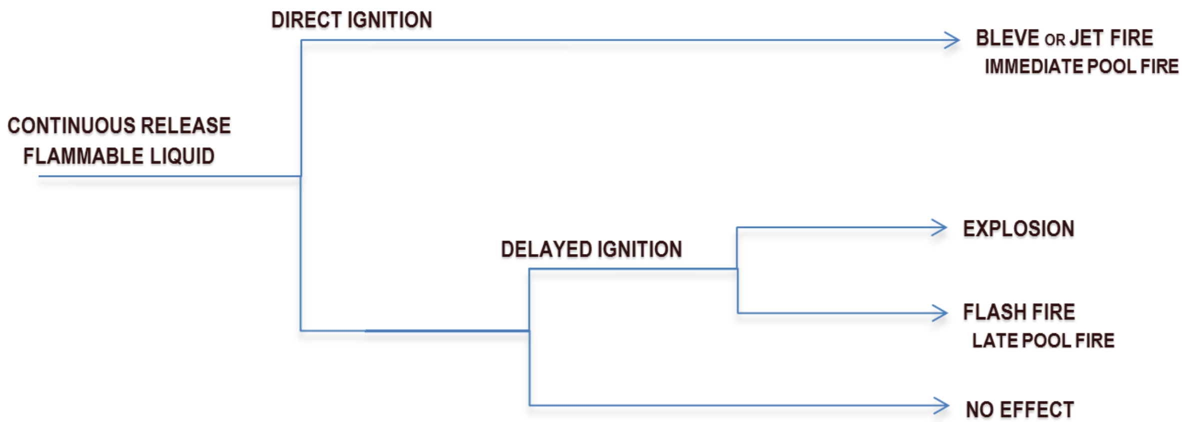


Figure 4-5: Event tree for a continuous release of a flammable liquid

4.6 The History of Incidents in the Liquefied Natural Gas (LNG) Industry

In the early years of the liquid natural gas (LNG) industry three incidents occurred at onshore facilities which resulted in fatalities. The outcome was the institutionalisation of more stringent operational and safety regulations in the industry.

The East Ohio Gas Company built the first commercial liquefaction LNG facility in Cleveland in 1941. As stainless-steel alloys were scarce due to the Second World War, a large new tank was constructed out of steel with low nickel content. Shortly after going into service the tank failed and LNG spilled into the street and stormwater system. 128 people were killed, 225 people were injured and about 30 acres were devastated due to the resultant fire.

Factors that were relevant to the incident developing was the incompatible nature of the material used to build the vessel, the absence of adequate bunding, the proximity of the facility to the residential area and the release from a second vessel due to the inadequate fire insulation of its support structure (US Bureau of Mines 1946).

Within the United States, proper precautions have been common place in all the LNG facilities built and placed in service since the Cleveland incident.

In the second incident, one of the concrete LNG storage tanks the Texas Eastern Transmission Corporation (TETCO) collapsed killing 37 construction workers inside. This commonly misunderstood to be an LNG incident; however, the subsequent investigation by the New York City Fire Department (1973) concluded that it was a construction accident.

The third and final incident to produce a fatality in the US occurred in October 1979 at an electrical substation at Cove Point Terminal in Maryland. LNG leaked through an inadequately tightened pump seal and vaporised. The vapours travelled a distance through an underground electrical conduit and entered the substation where no gas detectors were installed. The subsequent explosion resulted in one fatality, one severe injury and very severe damages to the substation.

This incident resulted in three major design code changes which are applicable to entire industry (National Transportation Safety Board 1980). As of 2014, no death or serious accident involving an LNG facility has occurred in the United States in 35 years.

Two other incidents are worth noting. In March 2014 an explosion and fire occurred at Northwest Pipeline LNG facility in Plymouth, Washington. One person was injured, the facility was damaged, including one of the LNG storage vessels, and the surrounding area was evacuated as a precaution to secondary incidents (The Williams Companies 2014). There were no fatalities. The cause of the incident is still under investigation.

Another is the explosion at the LNG facility in Skikda, Algeria, in January 2004 that resulted in the death of 27 people, injured about 80 others and resulted in extensive damage to the facility and even to neighbouring facilities. A boiler exploded setting off a chain reaction. The ultimate cause of the incident is still under investigation, but there is some speculation that siting, design, operational and management aspects could have played significant roles (The Pipeline & Gas Journal 2004). The LNG storage vessels themselves remained intact.

Ocean-going tanker transportation of liquefied natural gas (LNG) has a long record of safe operation. Only a few incidents have occurred since the first converted vessel delivered a cargo of LNG to the United Kingdom originating from Lake Charles, Louisiana, in January 1959. According to the US Department of Energy (2002) over the life of the industry eight marine incidents worldwide have resulted in spillage of LNG, with some hulls damaged due to cold fracture, but no cargo fires have occurred. Seven incidents were recorded not involving spillage, with two from groundings, but none of these had significant cargo loss. Furthermore, there have been no LNG fatalities related to shipping.

The LNG industry has an excellent safety record compared to refineries and other petrochemical plants (University of Houston Law Centre 2003). Worldwide there are 17 LNG liquefaction and export terminals, 40 import and regasification terminals and 136 LNG ships. The distribution of facilities in 2002 is illustrated in Figure 4-6. Approximately 120 million metric tons of LNG is handled every year. As of 2014, LNG has been safely delivered across the ocean for over 40 years. In that time there have been over 33 000 LNG carrier voyages, covering more than 60 million miles, without major accidents or safety problems either in port or on the high seas. Furthermore, LNG carriers frequently transit high traffic density areas.

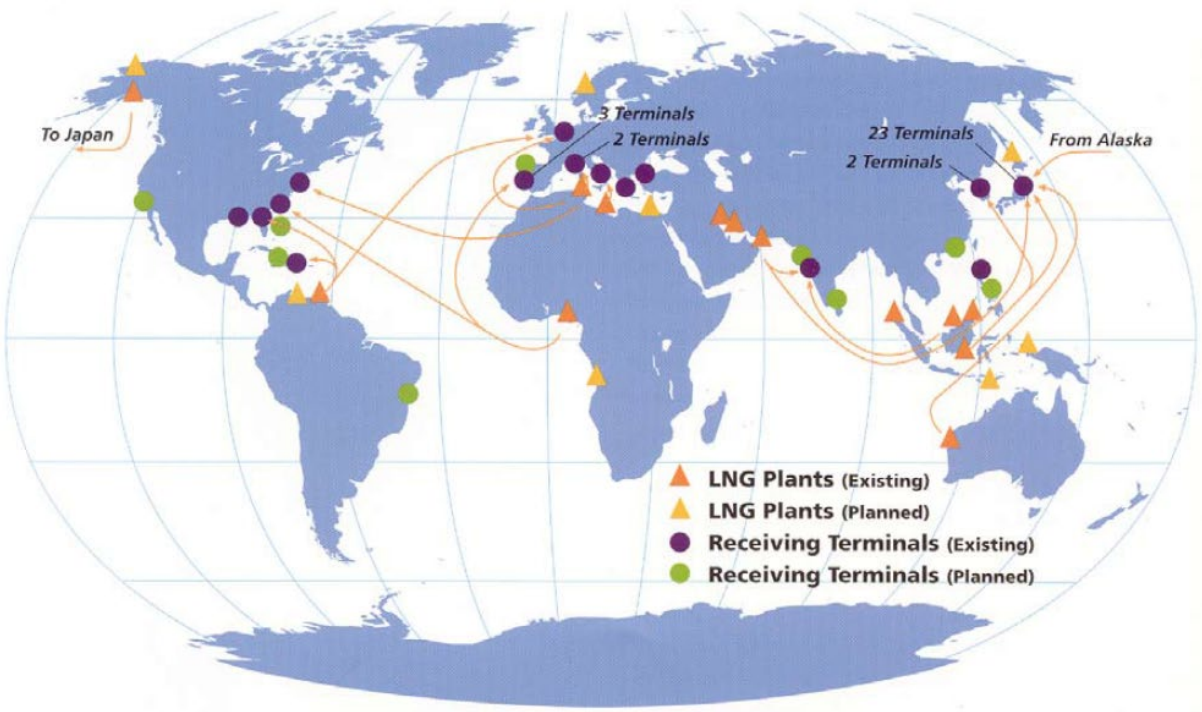


Figure 4-6: Worldwide distribution of LNG production plants and receiving terminals (Powers 2002)

Design requirements set forth by the US National Fire Protection Association address the protection of facilities from earthquakes. No LNG storage tank failures have occurred due to seismic activity. This is true even in Japan, which relies on LNG to meet all of its natural gas needs and is one of the most seismically active areas in the world.

In 2011 the largest earthquake and tsunami recorded in Japanese history, from the Great East Japan Earthquake, was the first seismic event to damage a Japanese LNG receiving facility, the Sendai City Gas Bureau Minato Works (Takei 2012). The facility was constructed according to seismic design requirements and the actual earthquake did almost no damage. Flooding by the tsunami did most of the damage, but there were no fatalities, LNG leaks or secondary hazards due to LNG. As a result, new standards are being developed to safeguard LNG facilities against tsunami damage.

Due to the properties of LNG, explosions are highly unlikely. According to the US Federal Energy Regulatory Commission (FERC), although a large amount of energy is stored in LNG, it cannot be released rapidly enough to cause the overpressures associated with an explosion. LNG vapours consisting mainly of methane mixed with air are not explosive in an unconfined environment.

However, it should be noted that the safety of LNG facilities and marine transport vessels over the decades has been a product of advanced technology, well-trained professionals, a thorough understanding of LNG risks, virtually fail-safe safety systems and procedures and rigidly adhered to standards, codes and regulations.

4.7 Historical Pipeline Incidents

Lessons from past incidents as well as operating experience can make a significant contribution to the selected hazard screening method and to its results. Furthermore, without reviewing historical accident reports, some aspects of the cause of the incident may go by without consideration. In this investigation, a review of historical pipeline spillage records from the USA, Europe, Australia and New Zealand was conducted.

The European Gas Pipeline Incident Data Group (EGIG), comprised of gas institutions from nine European countries, has collected data since 1970 about the performance of onshore transmission gas pipelines in Western Europe. The data has been analysed (EGIG 2016) to record the reported-on pipeline system development over time, quantify environmental performance and reveal trends in causes of spillages.

Considering the number of participants, the extent of the pipeline systems and the exposure period involved (from 1970 onwards for most of the companies), the EGIG database is a valuable and reliable source of information.

The primary failure frequency over the entire period from 1970 to 2016 was equal to 0.31 per 1000 km•yr and is lower than previously published figures. Figure 4-7 shows the steady decline in the primary failure rates and the failure frequencies of the five-year moving average.

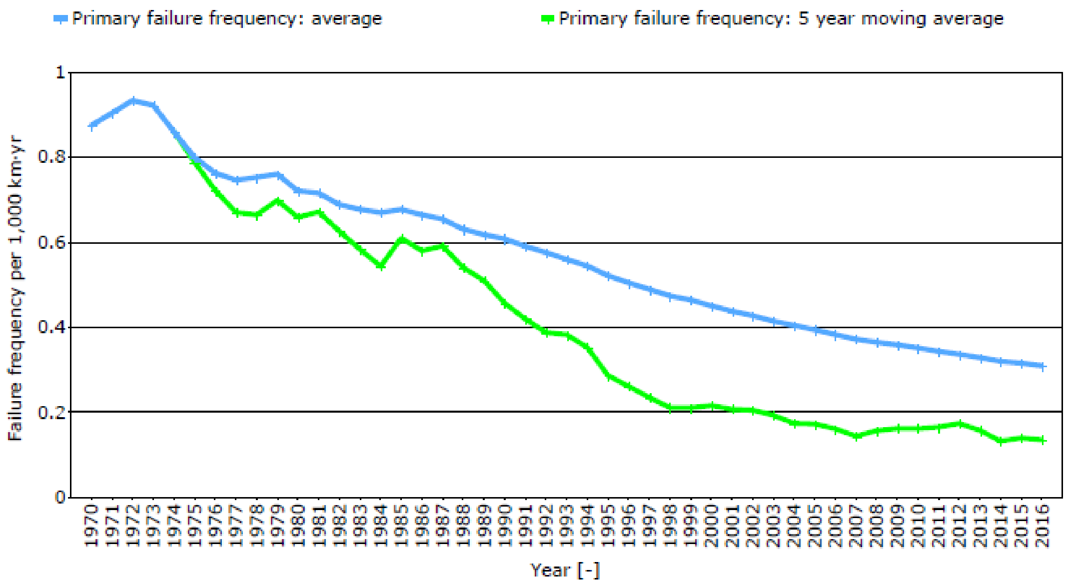


Figure 4-7: Natural gas incident frequency reduction trend from 1970 to 2016 (EGIG 2016)

Six different causes were identified as the primary failures, as given in Table 4-21 with external interference being the major cause.

Table 4-21: Primary failures: distribution per cause

Cause	Distribution (%)
External interference	28.37
Construction defect or material failure	17.79
Corrosion	25.0
Ground movement	14.9
Hot tap made in error	3.85
Other or unknown	10.1

4.7.1 Typical Causes of Pipeline Incidents

Typical causes of pipeline incidents include external interference, mechanical failure, corrosion, natural hazards and operational failures.

External interference (third party) is the most important mechanism of pipeline damage in terms of likelihood and volume spilled. This term means that someone other than the pipeline operator (a third party) damages the pipeline. This type of accident is normally a consequence of digging operations with mechanical diggers or, occasionally, by driving metal or wooden stakes into the ground. The result may be an immediate leak or a weakened part in the pipeline that might fail at some point in the future.

Mechanical failures are essentially unrehearsed failures of the pipe wall or welds. This may, for example, occur when the pipeline is used continuously at pressures considerably higher than the designed specification; this may lead to material fatigue. Alternatively, a weld may split open at a weak point (e.g., inclusion of a piece of slag or simply a thin portion). Although very uncommon, a pipe may fail due to stress on the steel, which would typically occur as a result of an incorrect installation.

Corrosion of a pipeline can be either external or internal. Where the pipe wall or a weld has been corroded away; the corrosion usually forms a very small hole or pinhole. Corrosion can result from an existing weak point on the pipe or weld or electrochemical differences between the soil and pipeline surface. This is generally difficult to predict or pinpoint since large holes from corrosion are very rare.

Natural hazards include flooding, landslides, earthquakes and sinkholes (undermining).

Operation failures cover operator error and the malfunction of pressure control and protection systems.

4.7.2 Other Factors

The EGIG database covered failure rates relating to pipeline diameter, wall thickness and depth of cover and the following conclusions were made:

- The small diameter pipelines are more vulnerable to external interference than larger diameter pipelines:
  - This can be attributed to the fact that small diameter pipelines can be more easily hooked up during ground works than bigger pipelines and to the fact that their resistance is often lower due to thinner wall thickness;
- The depth of cover is one of the leading indicators for the failure frequencies of pipelines:
  - Pipelines with a larger depth of cover have a lower primary failure frequency;
- Wall thickness is an effective protective measure against the impact of external interferences;
- More severe incidents like ruptures and holes occur mainly at pipelines with smaller diameters, a relatively small cover depth and with the pipeline having a thin wall thickness.

Corrosion is the third highest cause of gas leakage and occurs mainly in thin-walled pipelines (< 10 mm) with about 75% occurring in pipelines with wall thickness of less than 5 mm. Incidents of pipes with a wall thickness of 10 mm and above represent less than 2% of all corrosion failures.

4.7.3 Design Code

The design code for the pipeline was done according to the American Society of Mechanical Engineers ASME 31.4 code, which is an accepted international code.

The code prohibits designs and practices known to be unsafe and contains warnings where caution but not prohibition is warranted. The code specifically includes:

- Reference to acceptable material specifications and component standards, including dimensional and mechanical property requirements;
- Requirements for design of components and assemblies;
- Requirements and data for evaluation and limitation of stresses, reactions and movements associated with pressure, temperature change and other forces;
- Guidance and limitations on the selection and application of materials, components and joining methods;
- Requirements for the fabrication, assembly and installation of piping;
- Requirements for examination, inspection and testing of piping;
- Procedures for operation and maintenance that is essential to public safety including plans for:
  - Training;
  - Protecting pipelines from external and internal corrosion;
  - Reviewing changes in the surrounding environment.

4.7.4 Mitigation for Third-Party Damage and Mechanical Failure

4.7.4.1 Wall Thickness

A requirement of the ASME B31.8 code is to increase the strength (related to wall thickness) of the pipeline in areas of high existing and projected population density. Population density is a reasonable index of the possible consequences of a fire or explosion; in densely populated downtown areas, for example, the consequences of a pipeline failure would be significantly greater than in suburban, peri-urban or rural areas.

It is worth noting here that the EGIG incident database reported no incidents with wall thicknesses of more than 15 mm.

It is furthermore important to note that this risk assessment was based on the proposed wall thickness and does not assume that the use of the code wall thickness would automatically result in a low risk.

5 RISK ASSESSMENT

Risk assessment was done of each processing unit by firstly selecting a scenario and then completing consequence and outflow modelling. Consequences with possible impacts beyond the site boundary were retained for risk analysis of the unit.

Finally, the risk of the entire facility is determined as a combination of the risk calculated for each unit.

5.1 Phase 1

5.1.1 Description and Assumptions

Phase 1 of the project would consist of the following;

- Temporary Facilities
    - **LNG carrier**

      Expected deliveries of 52 times per year with 24-hour offloading.

- Permanent facilities
    - **FSRU**

      The FSRU will be permanently berthed and will receive the LNG from the LNG carrier. It will be 170 000 m^3 in size and will supply LNG to the road tanker loading facility. The FSRU will also be able to vaporise LNG to natural gas to supply fuel to the three power stations. For this study, the following is assumed:
        - The natural gas temperature will be raised to 0ºC and transported at 60 bar to the power station in 24 “NB underground pipeline, except for the jetty area, where the pipeline would be above ground.
        - The LNG will be transported to the gas distribution facility at 10 bar and -162ºC.

    - **Natural Gas Pipeline**

      The natural gas pipeline routing will be above ground at the jetty and continue underground to the power stations. The natural gas temperature will be raised to 0ºC and transported at 60 bar to the power station in 24 “NB pipeline.

      Due to the high pressure in the pipeline and specifically above the critical pressure of natural gas, the product is referred to as compressed natural gas (CNG).

    - **LNG Pipeline**
        - The natural gas pipeline routing will be above ground at the jetty and continue underground to the gas distribution facility and road tanker filling. For this study, it is assumed that the LNG would be transported at 800 t/d at 10 bar and -162ºC

    - **Gas Distribution Facility**

      At Phase 1 the gas distribution facility would consist of administration buildings and functions, pigging facilities and road tanker loading.

- **Road Loading Facility**
  The road loading facility will consist of 2 loading bays that will load with estimated loading of 40 x 20-ton LNG trucks per. This study assumed that each bay would be fully occupied i.e., operating 24 hours per day. The area of release was taken at 1200 m^3 (RIVM 2009).

5.1.2 Scenario Modelled

The scenarios modelled for Phase 1 of the project are given in Table 5-1.

Table 5-1: Scenarios modelled for Phase 1

Equipment	Scenario	Remarks
LNG Carrier	Collisions	Failure frequency as per Section 4.4.2.1 Ignition frequency as per Section Flash fire /VCE =0.6/0.4
	Offloading hoses	Failure frequency as per Section 4.4.2.1 Ignition frequency as per Section Flash fire /VCE =0.6/0.4
FSRU	Collision	Failure frequency as per Section 4.4.2.1 Ignition frequency as per Section Flash fire /VCE =0.6/0.4
	Offloading hoses	Failure frequency as per Section 4.4.2.1 Ignition frequency as per Section 4.4.2.1 Flash fire /VCE =0.6/0.4
	Regasification Unit and compressor	Failure frequency as per Section 4.4.2.1 Ignition frequency as per Section 4.4.2.1Flash fire /VCE =0.6/0.4
Pipelines	Failure	Failure frequency as per Section 4.4.2.1 Ignition frequency as per Section 4.4.2.1Flash fire /VCE =0.6/0.4
	Leak	Failure frequency as per Section 4.4.2.1 Ignition frequency as per Section 4.4.2.1Flash fire /VCE =0.6/0.4
Road Tanker	Failure	Failure frequency as per Section 4.4.2.1 Ignition frequency as per Section 4.4.2.1Flash fire /VCE =0.6/0.4 Hours on site = 8 h/day, 5 days /week
	Loss from largest nozzle	Failure frequency as per Section 4.4.2.1 Ignition frequency as per Section 4.4.2.1Flash fire /VCE =0.6/0.4 Hours on site = 8 h/day, 5 days /week
Tanker hose	Failure	Failure frequency as per Section 4.4.2.1 Ignition frequency as per Section 4.4.2.1Flash fire /VCE =0.6/0.4 Hours on site = 8 h/day, 5 days /week
Tanker hose	Leak	Failure frequency as per Section 4.4.2.1 Ignition frequency as per Section 4.4.2.1Flash fire /VCE =0.6/0.4 Hours on site = 8 h/day, 5 days /week

5.1.3 LNG Carrier and Offloading

- **LNG Carrier**

LNG would be imported from a tanker with a nominal capacity of 170 000 m^3. The LNG within the tanker would be contained in a number of tanks at approximately -162°C with no overpressure. LNG would be transferred to the FSRU via the storage via four offloading arms at a shut-off pressure of 6 barg.

A loss of containment of LNG could occur due to the following reasons:

- Failure of the LNG tanks on the carrier;
- Collision with other ships or barge; and,
- Failure of the ship transfer arm or hose.

The potential amount of released material that should be considered as a result of a collision is 126 m^3 in 1800 seconds for a large release (RIVM 2009).

The potential major events resulting in fires and explosions is shown in Figure 5-1 to the 1% fatality. The downward distance is shown from a westerly wind, with the orange curve indicating the largest 1% endpoint from all wind directions, that can extend downwind to a maximum distance of 205 m. The impacts would be localised and could only occur during the offloading period.

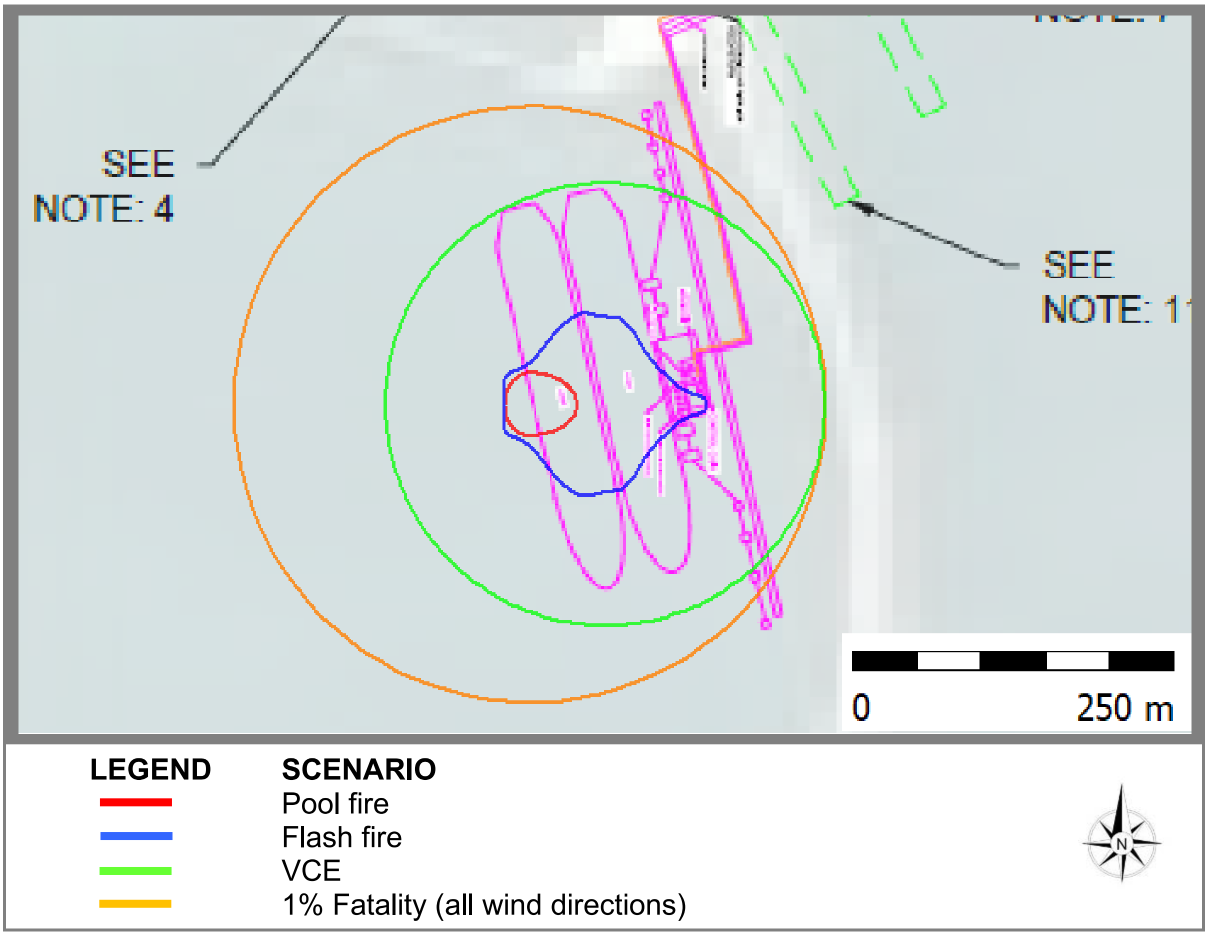


Figure 5-1: The maximum extent of fires and explosions, to the 1% fatality, resulting from an LNG release from a single LNG carrier

The release forms a pool on the water surface that evaporates very rapidly resulting in the flammable cloud and the vapour cloud explosion.

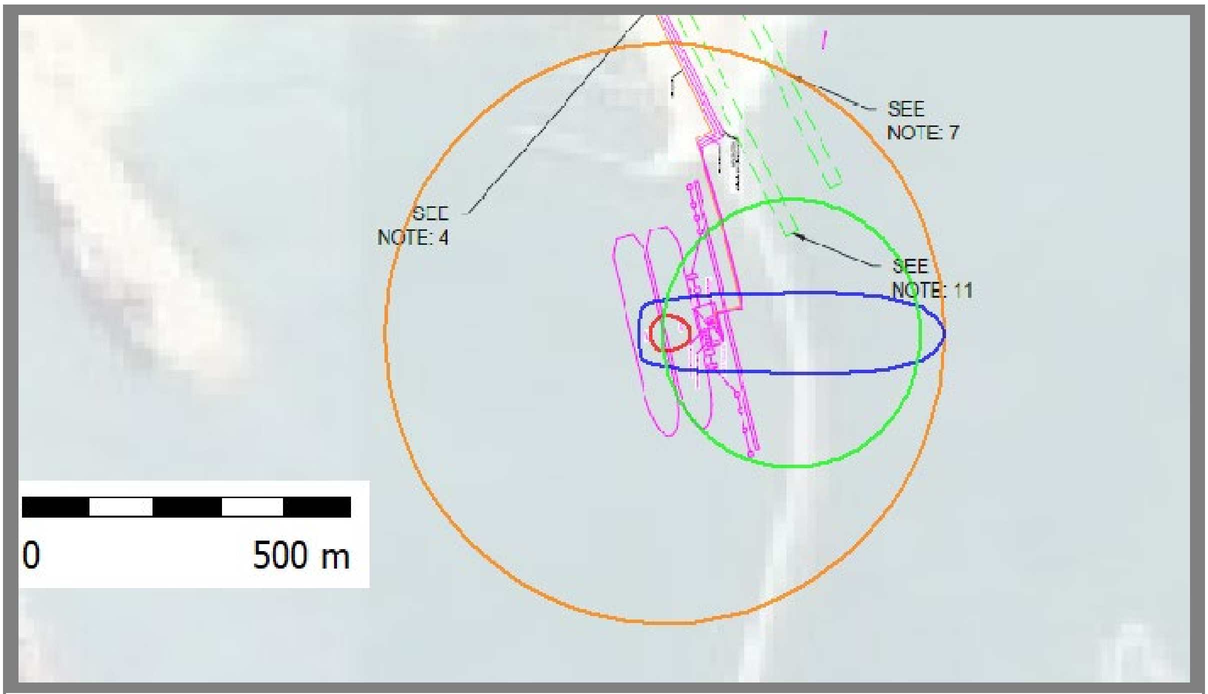
In this instance the largest distance to the endpoint is dominated by the VCE at low wind speeds.

- **Offloading Hose Failure**

The offloading from the LNG carrier was assumed to offload at a maximum of 3000 t/d for each hose. For this study, the ships pumps are assumed to operate at a pressure of 6 bar and will operate continuously until the LNG carrier is empty. At that stage, the operation will continue with the fully loaded carrier, also docked at the jetty.

The maximum extent from fires and explosions from a full-bore rupture of the loading arm is shown in Figure 5-2. The downward distance is shown from a westerly wind, with the orange curve indicating the largest 1% endpoint from all wind directions.

In this instance the largest distance to the endpoint is dominated by the VCE at medium wind speeds.



LEGEND	SCENARIO
(red)	Pool fire
(blue)	Flash fire
(green)	VCE
(orange)	1% Fatality (all wind directions)

Figure 5-2: The maximum extent of fires and explosions, to the 1% fatality, resulting from a large release from the offloading hose.

5.1.4 FSRU and Offloading

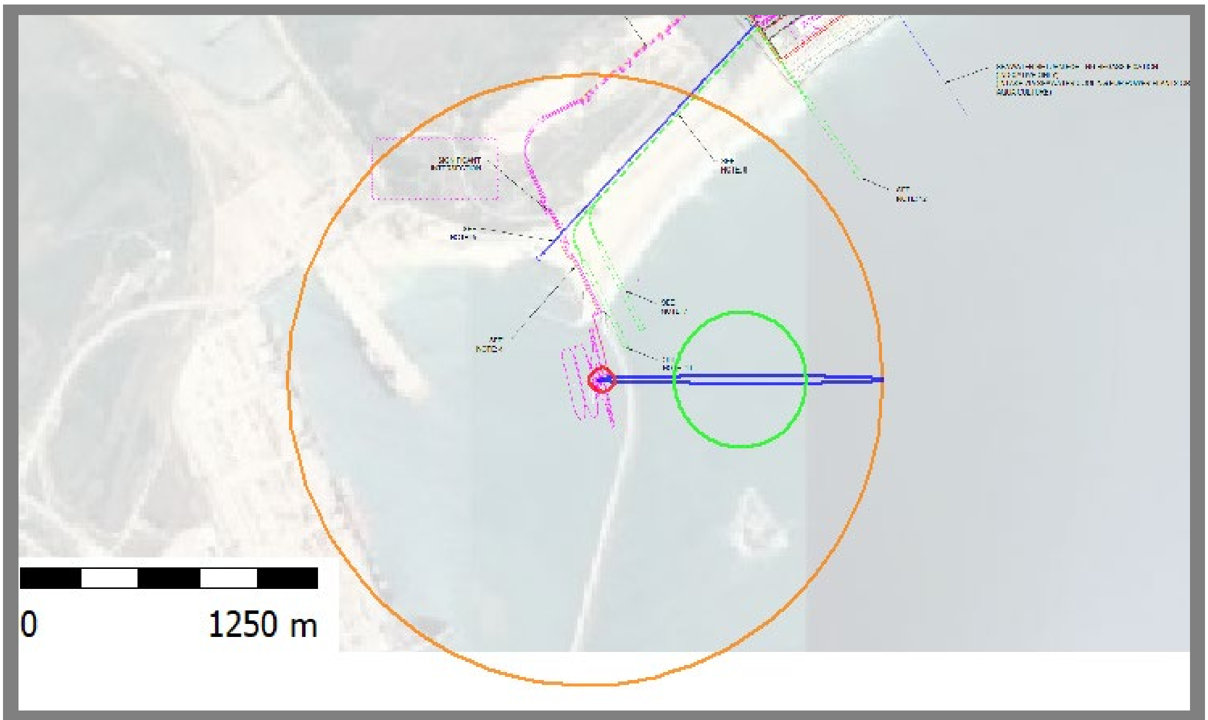
The FSRU is similar to the LNG carrier and would have similar consequences with regards to collisions as described in Section 5.1.3. and thus, will not be repeated. The other units associated on the FSRU will be discussed below.

- **Regasification & Compressor**

The regasification and compressor assume two identical units having a 50% capacity each. The regasification would increase and compressor would send CNG into the pipeline at 0°C and 60 bar.

The maximum extent from fires and explosions from failure of the compressor discharge is shown in Figure 5-3. The downward distance is shown from a westerly wind, with the orange curve indicating the largest 1% endpoint from all wind directions.

The maximum distance from this scenario is the turbulent free jet at a low windspeed extending 1262 m from the release. The jet is narrow and thus impacts from this jet will be limited to the immediate area of the jet.



LEGEND	SCENARIO
(red line)	Jet fire
(blue line)	Flash fire
(green line)	VCE
(yellow line)	1% Fatality (all wind directions)

Figure 5-3: The maximum extent of fires and explosions, to the 1% fatality, resulting from a large release from the regasification and compressor on the FSRU

5.1.5 LNG Pipeline

The cold LNG will be transported from the FSRU to the gas distribution facility via a pipeline. Initially the pipeline would be above ground to the end of the jetty and then travel underground to the gas distribution facility.

1. This study assumes that the LNG will be transported at a pressure of 10 bar, -162ºC and that the maximum pool formed would be 1200 m^2 for the above ground pipeline at the jetty and 3000 m^3 for the below ground pipeline.

The maximum extent to the 1 % fatality for the above and below ground pipelines are given in Figure 5-4 and Figure 5-5 respectfully. The maximum distances occur at a low wind speed. For the below ground pipeline, the low temperature would evaporate rapidly and carried downwind to an ignition source. The maximum downward distance would be from a low windspeed and would be considerably shorter from a higher windspeed.

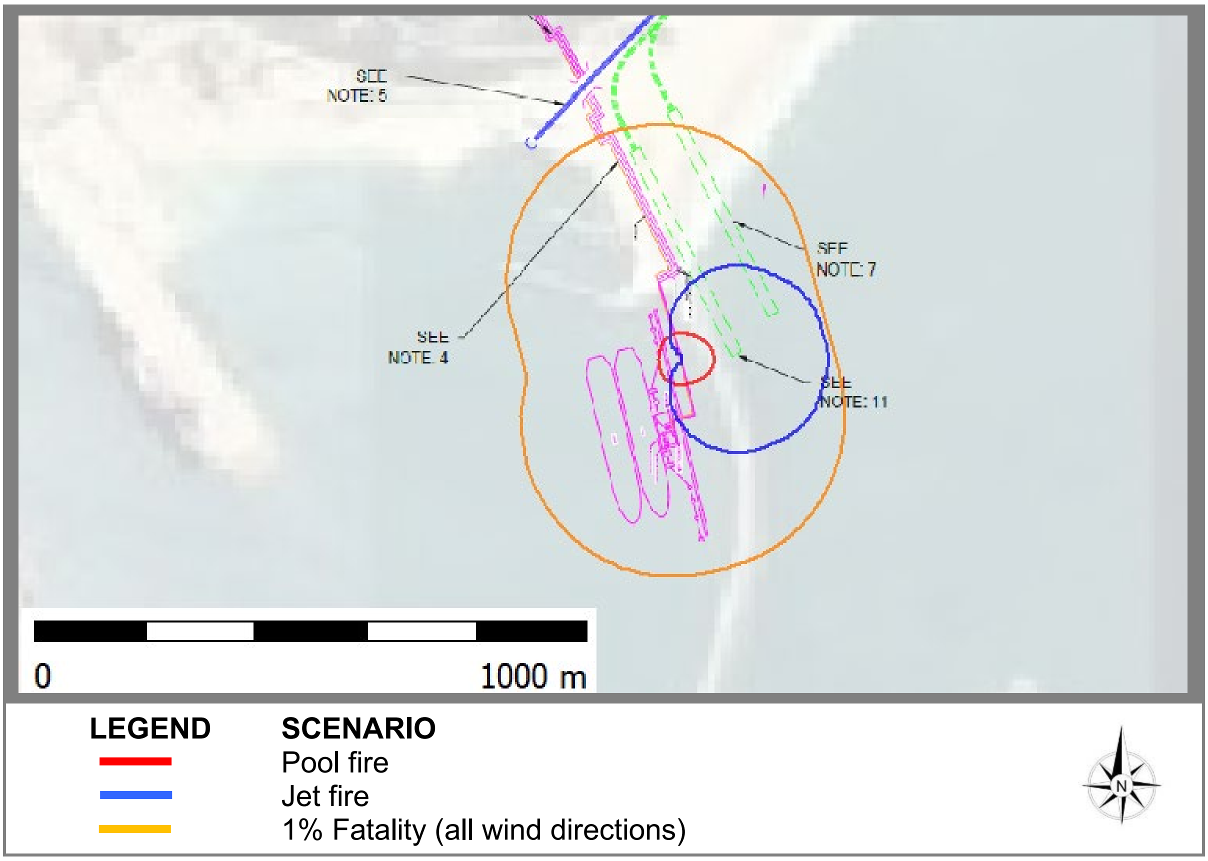


Figure 5-4: The maximum extent of fires and explosions, to the 1% fatality, resulting from a large release from the above ground section of the pipeline

LEGEND	SCENARIO
Red line	Pool fire
Blue line	Flash fire
Green line	VCE
Orange line	1% Fatality (all wind directions)

Figure 5-5: The maximum extent of fires and explosions, to the 1% fatality, resulting from a large release from below ground section of the pipeline

5.1.6 Compressed Natural Gas (CNG) Pipeline

CNG from the FSRU would be sent to the power plants. Initially the pipeline would be above ground to the end of the jetty and then travel underground to the power plants.

For this study the following as assumed:

1. The pipeline: 60 bar
2. Operating temperature: 0ºC
3. Pipeline diameter: 24” NB
4. Flow rate: 8510 m^3/h at operating conditions
5. Release orientation of above ground pipeline: horizontal
6. Release orientation of below ground pipeline: vertical

In accordance with the IGEM/TD/2 and PD 8010-3 standard, the belowground pipeline develops a fireball with a crater and then followed by a jet fire.

The maximum extent to the 1 % fatality for the above and below ground pipelines are given in Figure 5-6. The maximum distances occur at a low wind speed for the horizontal release from an above ground pipeline.

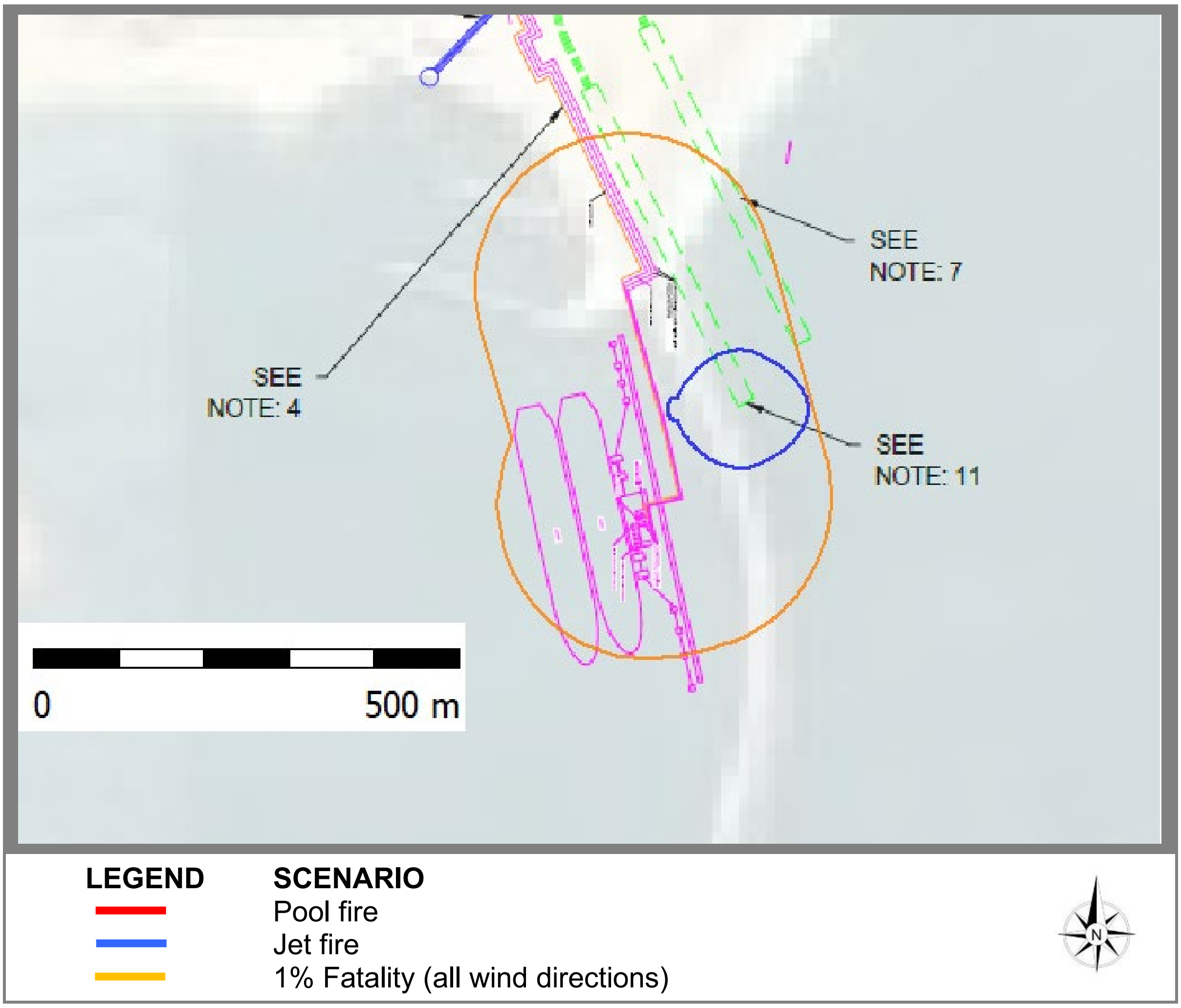


Figure 5-6: The maximum extent of jet fires, to the 1% fatality, resulting from a large release from the above ground section of the pipeline

For the below ground pipeline, the release is assumed to be horizontal, the initial release would be a fireball followed by a jet fire. The greatest extent will be due to a jet fire at a high windspeed, as shown in Figure 5-7 and could extend 61 m downwind from the release.

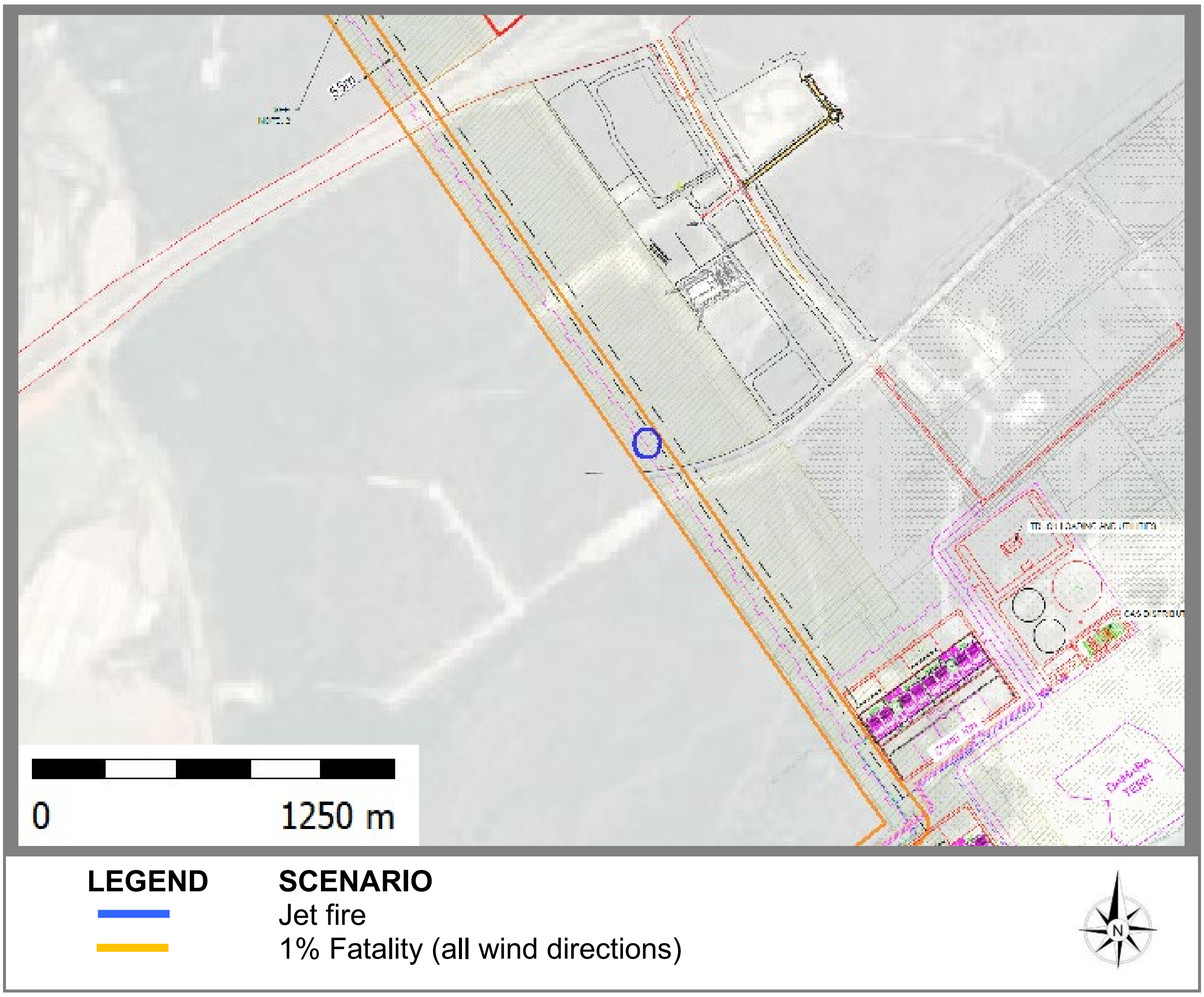


Figure 5-7: The maximum extent of fires and explosions, to the 1% fatality, resulting from a large release from a below ground section of the pipeline

5.1.7 Gas distribution Facility

During Phase 1 the gas distribution facility would receive cryogenic LNG via the pipeline from the FSRU. The LNG would be used to fill road tankers in two loading bays. A maximum of 40 x 20 t tankers would be loaded per day from two loading bays.

The s maximum extent from a loss of containment at the riad loading bay. The study assumed the maximum extent for the LNG spreading was capped at 1200 m^2. The maximum extent to the 1% fatality, from a large release with an ignition source is shown in Figure 5-8. In this instance, the largest downward distance was due from the catastrophic failure from a road tanker, at a low wind speed. At higher wind speeds, the downward distance decreases considerably.

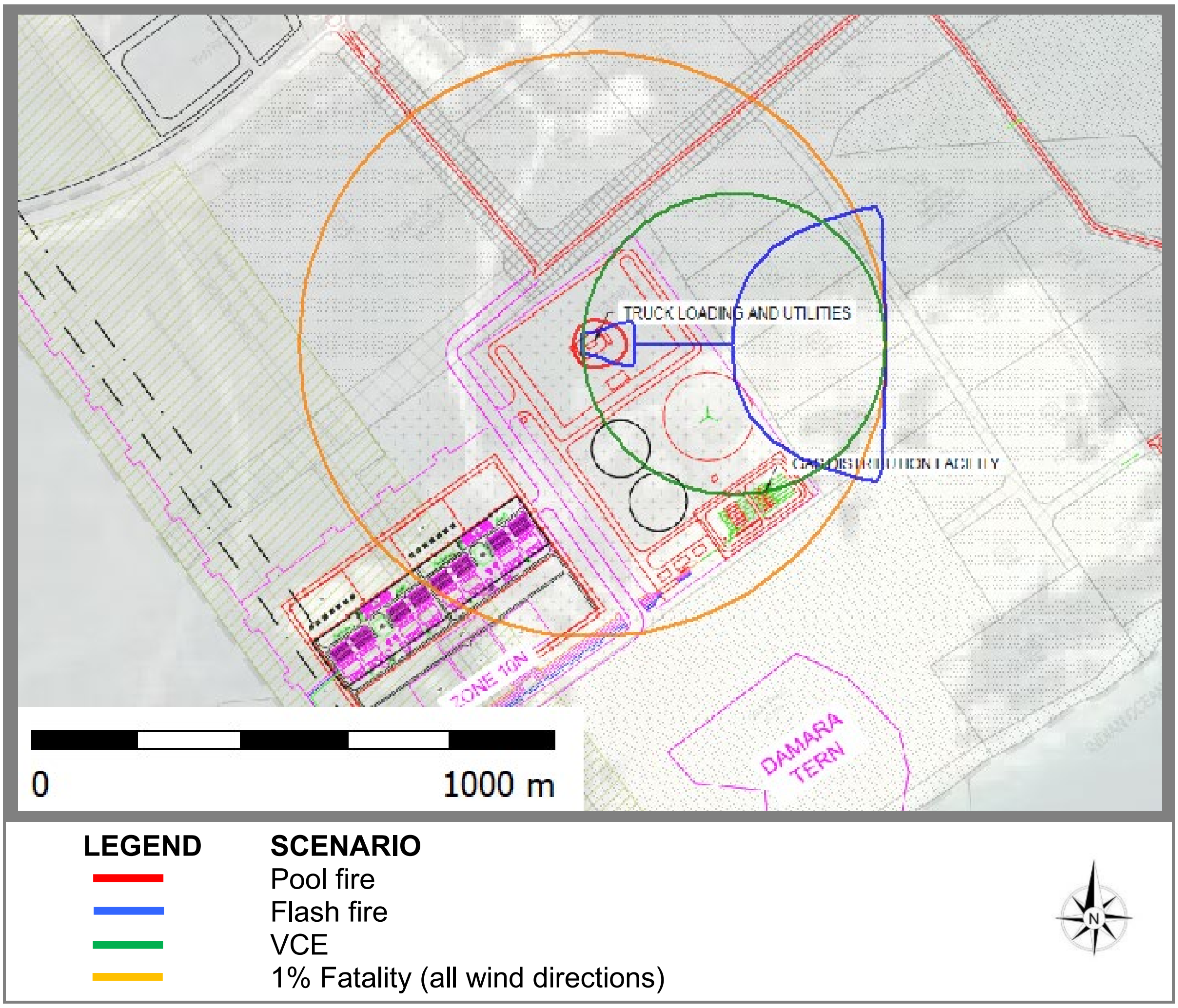


Figure 5-8: The maximum extent of fires and explosions, to the 1% fatality, resulting from a large release at the LNG road gantry

5.1.7.1 Summary of Impacts

Maximum distances from the point of release to the 1% fatality are summarised for each scenario in Table 5-2.

Table 5-2: Maximum distance to 1% fatality from the point of release

Scenarios	Max. Distance to 1% Fatality (m)
FSRU Collision	
FSRU Collision	205
LNG Gantry	
LNG Tanker - Catastrophic failure	601
LNG Tanker - Leak via largest nozzle	83
LNG Tanker hose failure - Failure	81
LPG Tanker hose - Leak	5
Pipeline gantry -Pipeline failure	205
Pipeline gantry -Pipeline leak	118
Pipeline - CNG above Ground	
Local cloud fire	50
Pipeline failure	176
Pipeline leak	61
Pipeline - CNG below ground	
Local cloud fire	50
Pipeline failure	61
Pipeline leak	36
Pipeline - LNG below ground	
Pipeline failure	105
Pipeline leak	52
Pipeline - LNG above ground	
Pipeline failure	284
Pipeline leak	186
Ship Collision	
Ship Collision	205

Ship Offloading Hose	
Ship transfer hose- Full bore hole	309
Ship transfer hose- Leak	106

5.1.8 Maximum Individual Risk

5.1.8.1 Jetty Operations

The risk isopleths for the jetty operations are shown in Figure 5-9. The risks of 1 x 10^{-4} fatalities per person per year would be unacceptable to the general public and would be located on the FSRUs, primarily associated with the regasification and compression of the natural gas. As these isopleths would be not extend beyond the jetty area, the risks would not be considered unacceptable.

The risks of 1 x 10^{-6} fatalities per person per year extending beyond the site boundary would classify the facility as a Major Hazard Installation. As this isopleth is far from the site boundary, the risks to the general public would be acceptable.

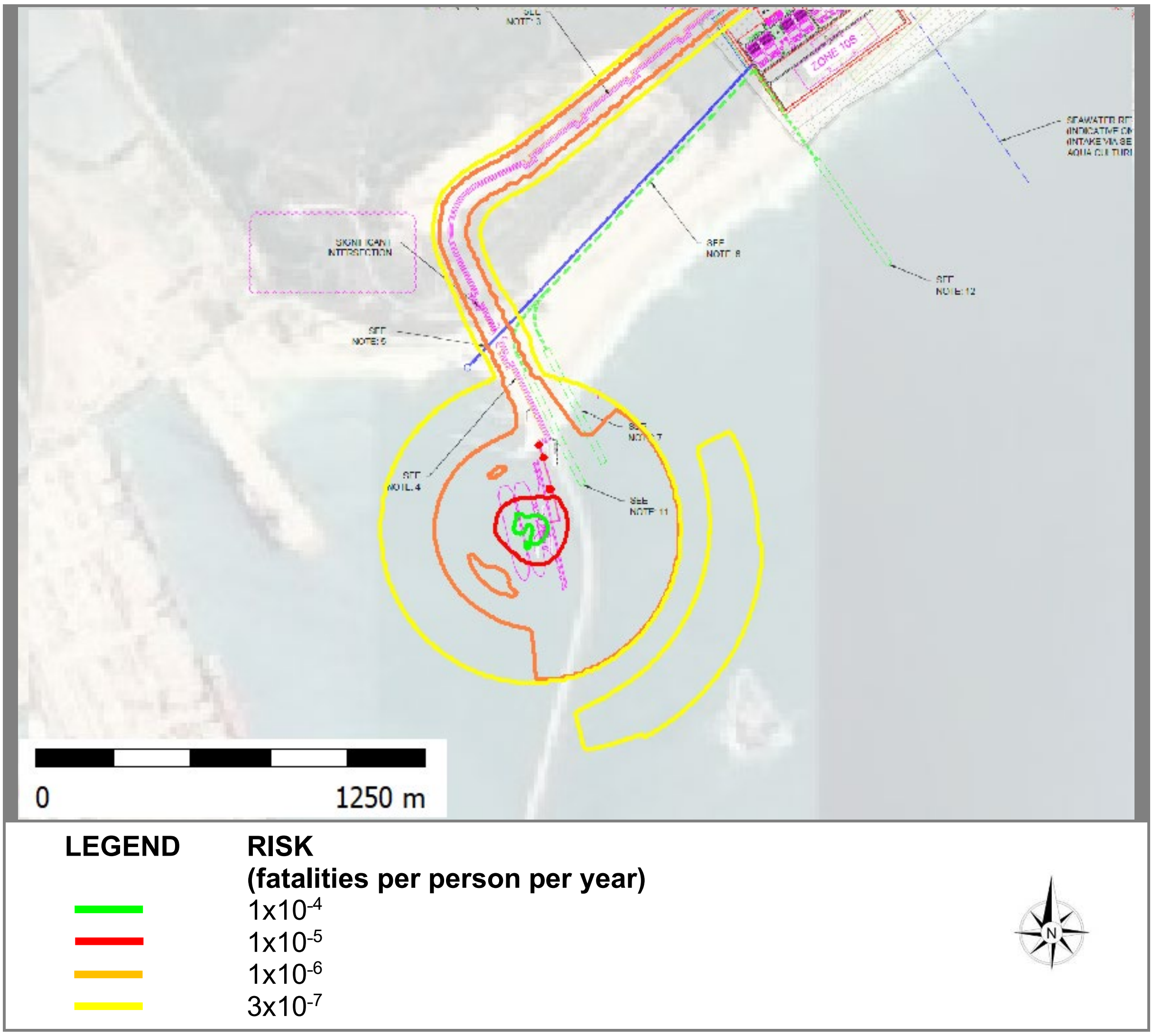


Figure 5-9: Risk isopleths for the jetty operations

5.1.8.2 LNG Road Loading

The risk isopleths for the LNG road loading is shown in Figure 5-10. The risk would be located within the loading area and would not impact facilities beyond the loading area.

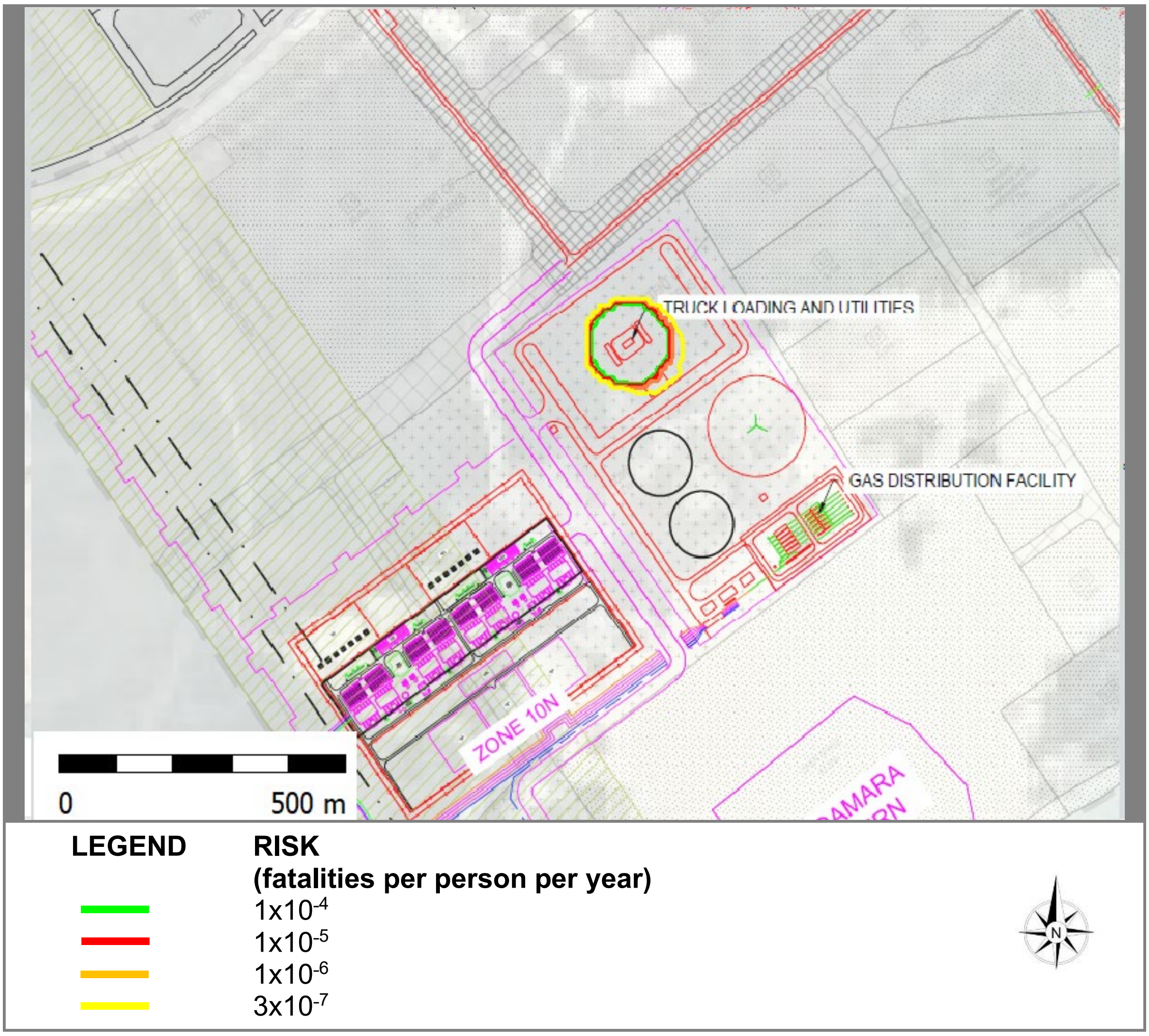


Figure 5-10: Risk isopleths for the LNG road loading operations

5.1.8.3 Pipeline Risks

The pipelines cover both the LNG and CNG pipelines. The jetty section has above ground pipelines with the remaining pipelines being underground. The combined pipeline risks are shown in Figure 5-11.

Risks greater than $1x10^{-4}$ fatalities per person per year, considered tolerable for industrial areas but excessive for the general public and residential areas, were not reached.

The risk of $1x10^{-6}$ fatalities per person per year isopleth extends to a maximum of 46 m from the pipeline and remains within the Coega SEZ, having limited impacts onto neighbouring facilities and the general public outside of the Coega SEZ. Thus, the LNG and CNG pipelines **would not be classified as a Major Hazard Installation**.

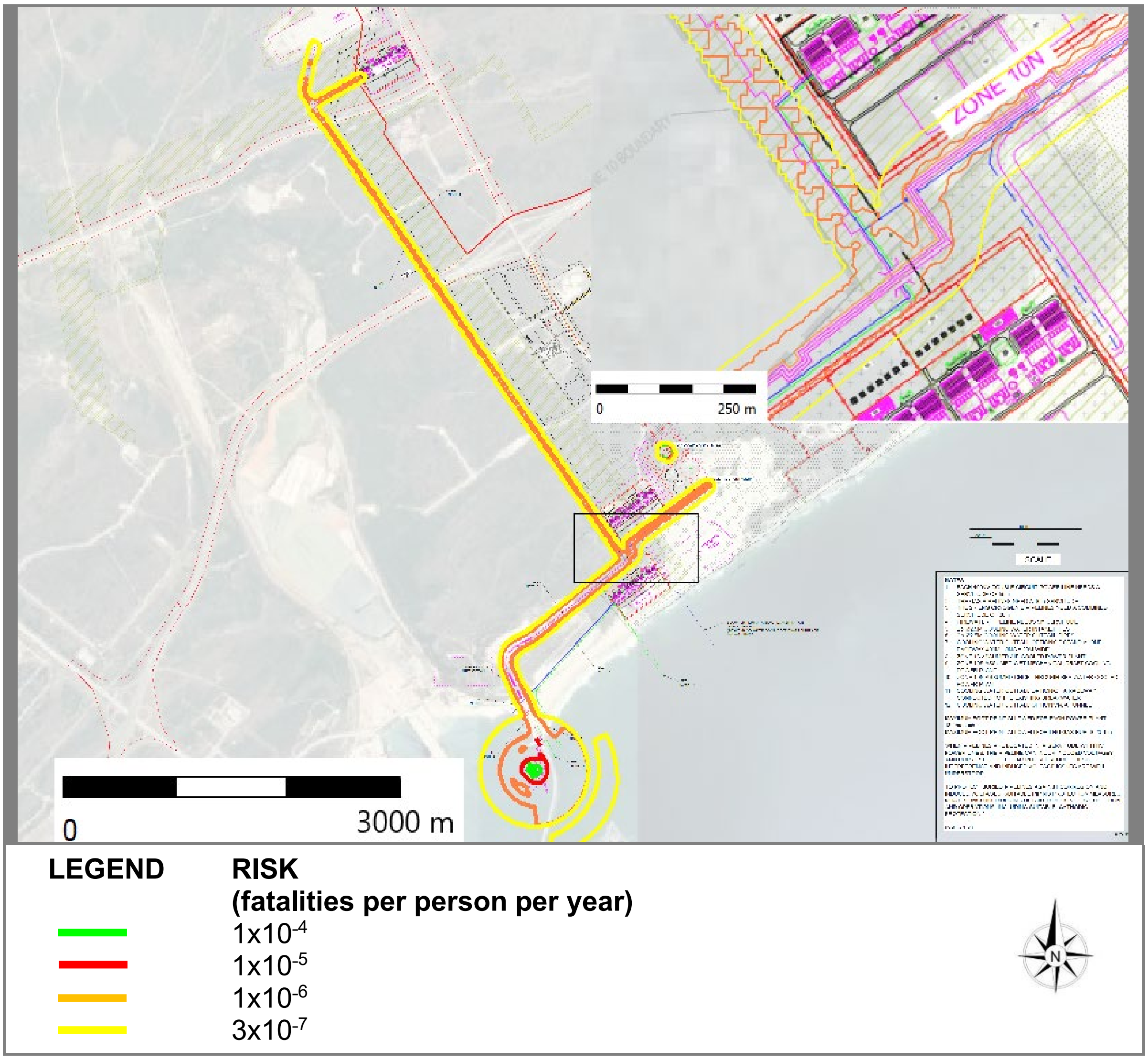


Figure 5-11: Lethal probability isolines associated with the LNG and CNG pipelines

5.2 Phase 2

5.2.1 Description and Assumptions

Phase 2 of the project would consist of the following;

- Temporary facilities
  - **LNG carrier.**

    Expected deliveries of 52 times per year with 24-hour offloading.

  - **LNG pipeline,**
    - The natural gas pipeline routing will be above ground at the jetty and continue underground to the gas distribution facility and road tanker filling. For this study, it is assumed that the LNG would be transported at 800 t/d at 10 bar and -162ºC.
    -
  - **Gas distribution facility**
    - LNG storage.

      The FSRU will be replaced with 2 x 160 000 m^3 storage tanks. Boil off gases would be sent to the Cold Vent.
    - Road loading facility.

      The road loading facility will consist of 2 loading bays that will load with estimated loading of 40 x 20-ton LNG trucks per. This study assumed that each bay would be fully occupied i.e., operating 24 hours per day. The area of release was taken at 1200 m^3 (RIVM 2009).

  - **Natural gas pipeline**

    Phase 2 operations would require the LNG to be gasified close to the LNG storage transported to the power stations as a compressed natural gas.

    The natural gas temperature will be raised to 0ºC and transported at 60 bar to the power station in 24 “NB pipeline.

Some of the units of Phase 2 are identical to that of Phase 1. Thus, this section may contain some repetition, with the purpose of reading this section without reference to Phase 1 part of the report.

5.2.2 Scenario Modelled

The scenarios modelled for Phase 2 of the project are given in Table 5-3.

Table 5-3: Scenarios modelled for Phase 2

Equipment	Scenario	Remarks
LNG Carrier	Collisions	Failure frequency as per Section Ignition frequency as per Section 4.4.2.1 Flash fire /VCE =0.6/0.4
	Offloading hoses	Failure frequency as per Section 4.4.2.1 Ignition frequency as per Section 4.4.2.1 Flash fire /VCE =0.6/0.4
Pipelines	Failure	Failure frequency as per Section 4.4.2.1 Ignition frequency as per Section 4.4.2.1 Flash fire /VCE =0.6/0.4
	Leak	Failure frequency as per Section 4.4.2.1 Ignition frequency as per Section 4.4.2.1Flash fire /VCE =0.6/0.4
LNG Storage	Failure	Failure frequency as per Section 4.4.2.1 Ignition frequency as per Section 4.4.2.1 Flash fire /VCE =0.6/0.4
	Loss of containment in 10 minutes	Failure frequency as per Section 4.4.2.1 Ignition frequency as per Section 4.4.2.1 Flash fire /VCE =0.6/0.4
Road Tanker	Failure	Failure frequency as per Section 4.4.2.1 Ignition frequency as per Section 4.4.2.1 Flash fire /VCE =0.6/0.4 Hours on site = 8 h/day, 5 days /week
	Loss from largest nozzle	Failure frequency as per Section 4.4.2.1 Ignition frequency as per Section 4.4.2.1Flash fire /VCE =0.6/0.4 Hours on site = 8 h/day, 5 days /week
Tanker hose	Failure	Failure frequency as per Section 4.4.2.1 Ignition frequency as per Section 4.4.2.1Flash fire /VCE =0.6/0.4 Hours on site = 8 h/day, 5 days /week
Tanker hose	Leak	Failure frequency as per Section 4.4.2.1 Ignition frequency as per Section 4.4.2.1Flash fire /VCE =0.6/0.4 Hours on site = 8 h/day, 5 days /week

5.2.3 LNG Carrier and Offloading

- **LNG Carrier**

LNG would be imported from a tanker with a nominal capacity of 170 000 m^3. The LNG within the tanker would be contained in a number of tanks at approximately -162°C with no overpressure. LNG would be transferred to the FSRU via the storage via four offloading arms at a shut-off pressure of 6 barg.

A loss of containment of LNG could occur due to the following reasons:

- Failure of the LNG tanks on the carrier;
- Collision with other ships or barge; and,
- Failure of the ship transfer arm or hose.

The potential amount of released material that should be considered as a result of a collision is 126 m^3 in 1800 seconds for a large release (RIVM 2009).

The potential major events resulting in fires and explosions is shown in Figure 5-12 to the 1% fatality. The downward distance is shown from a westerly wind, with the orange curve indicating the largest 1% endpoint from all wind directions, that can extend downwind to a maximum distance of 205 m. The impacts would be localised and could only occur during the offloading period.

The release forms a pool on the water surface that evaporates very rapidly resulting in the flammable cloud and the vapour cloud explosion.

In this instance the largest distance to the endpoint is dominated by the VCE at low wind speeds.

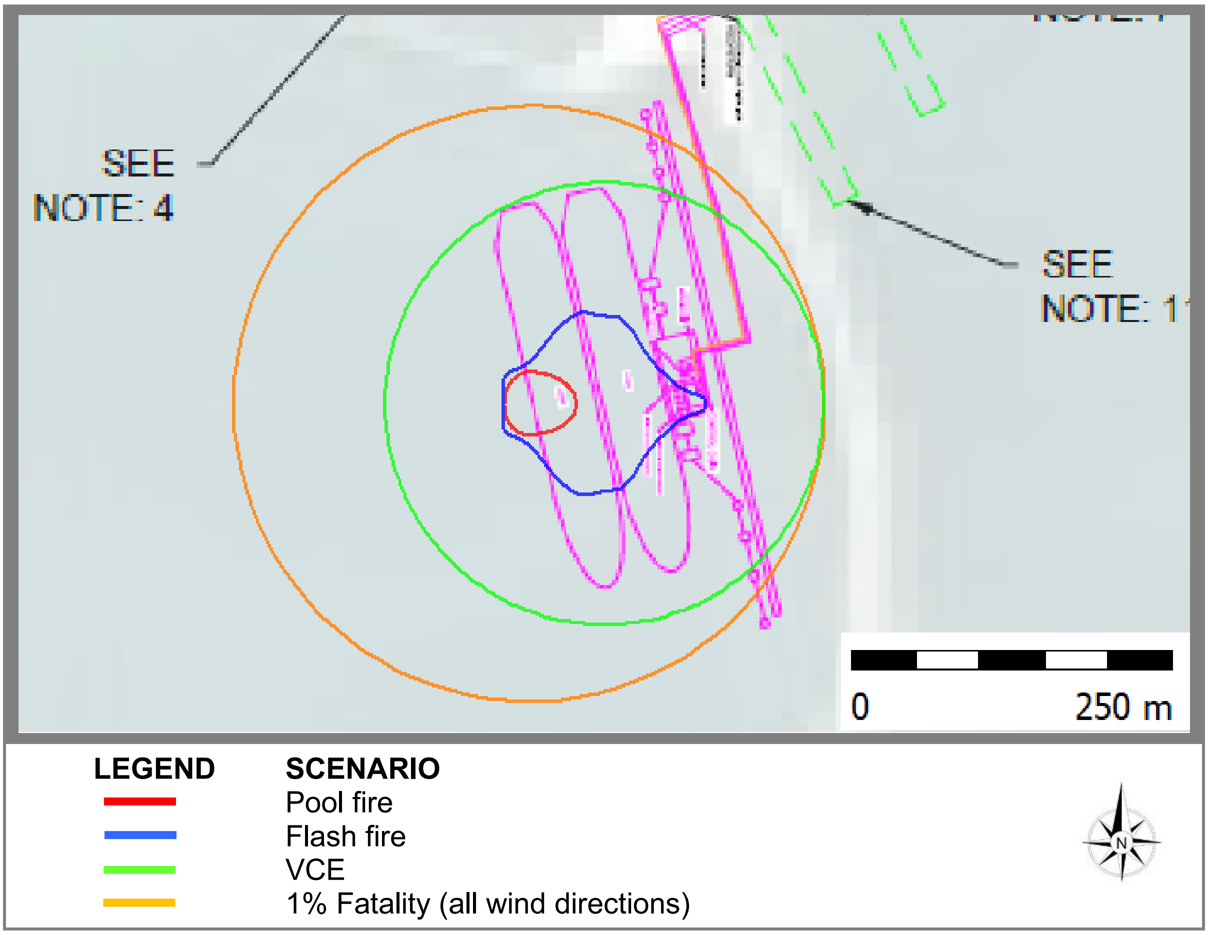


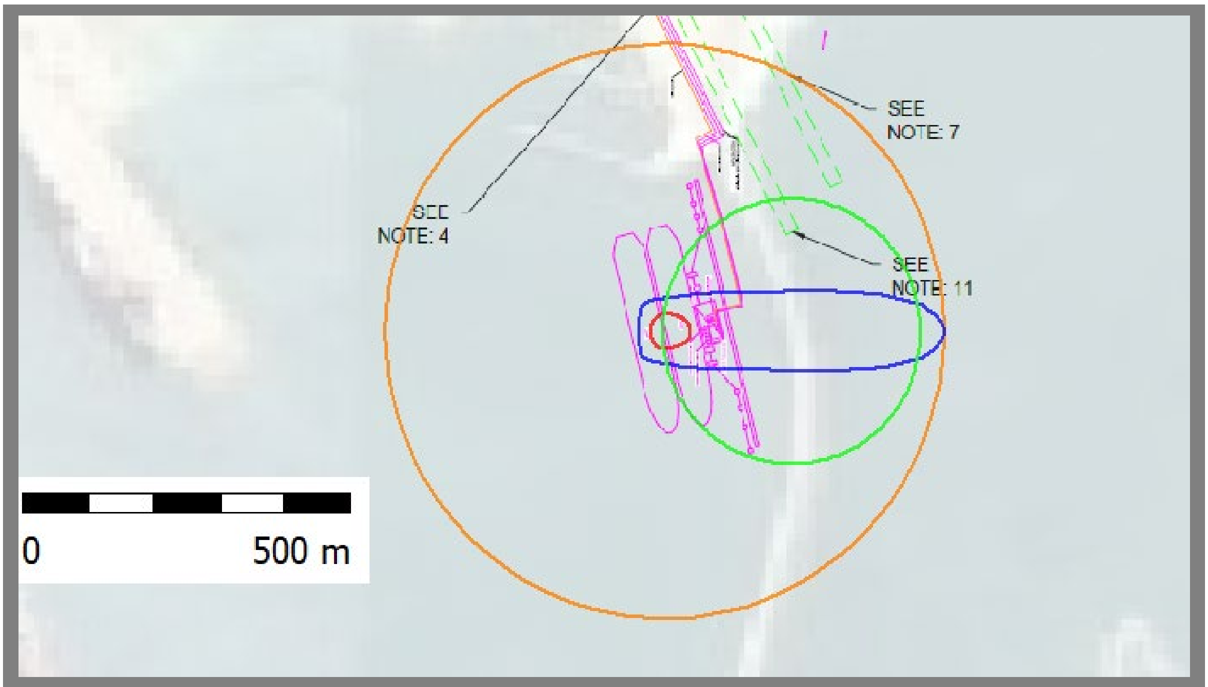
Figure 5-12: The maximum extent of fires and explosions, to the 1% fatality, resulting from an LNG release from a single LNG carrier

- **Offloading Hose Failure**

The offloading from the LNG carrier was assumed to offload at a maximum of 3000 t/d for each hose. For this study, the ships pumps are assumed to operate at a pressure of 6 bar and will operate continuously until the LNG carrier is empty. At that stage, the operation will continue with the fully loaded carrier, also docked at the jetty.

The maximum extent from fires and explosions from a full-bore rupture of the loading arm is shown in Figure 5-13. The downward distance is shown from a westerly wind, with the orange curve indicating the largest 1% endpoint from all wind directions.

In this instance the largest distance to the endpoint is dominated by the VCE at medium wind speeds.



LEGEND	SCENARIO
(red)	Pool fire
(blue)	Flash fire
(green)	VCE
(orange)	1% Fatality (all wind directions)

N

Figure 5-13: The maximum extent of fires and explosions, to the 1% fatality, resulting from a large release from the offloading hose.

5.2.4 LNG Pipeline

The cold LNG will be transported from the FSRU to the gas distribution facility via a pipeline. Initially the pipeline would be above ground to the end of the jetty and then travel underground to the gas distribution facility.

This study assumes that the LNG will be transported at a pressure of 10 bar, -162ºC and that the maximum pool formed would be 1200 m^2 for the above ground pipeline at the jetty and 3000 m^3 for the below ground pipeline.

The maximum extent to the 1 % fatality for the above and below ground pipelines are given in Figure 5-14 and Figure 5-15 respectfully. The maximum distances occur at a low wind speed. For the below ground pipeline, the low temperature would evaporate rapidly and carried downwind to an ignition source. The maximum downward distance would be from a low windspeed and would be considerably shorter from a higher windspeed.

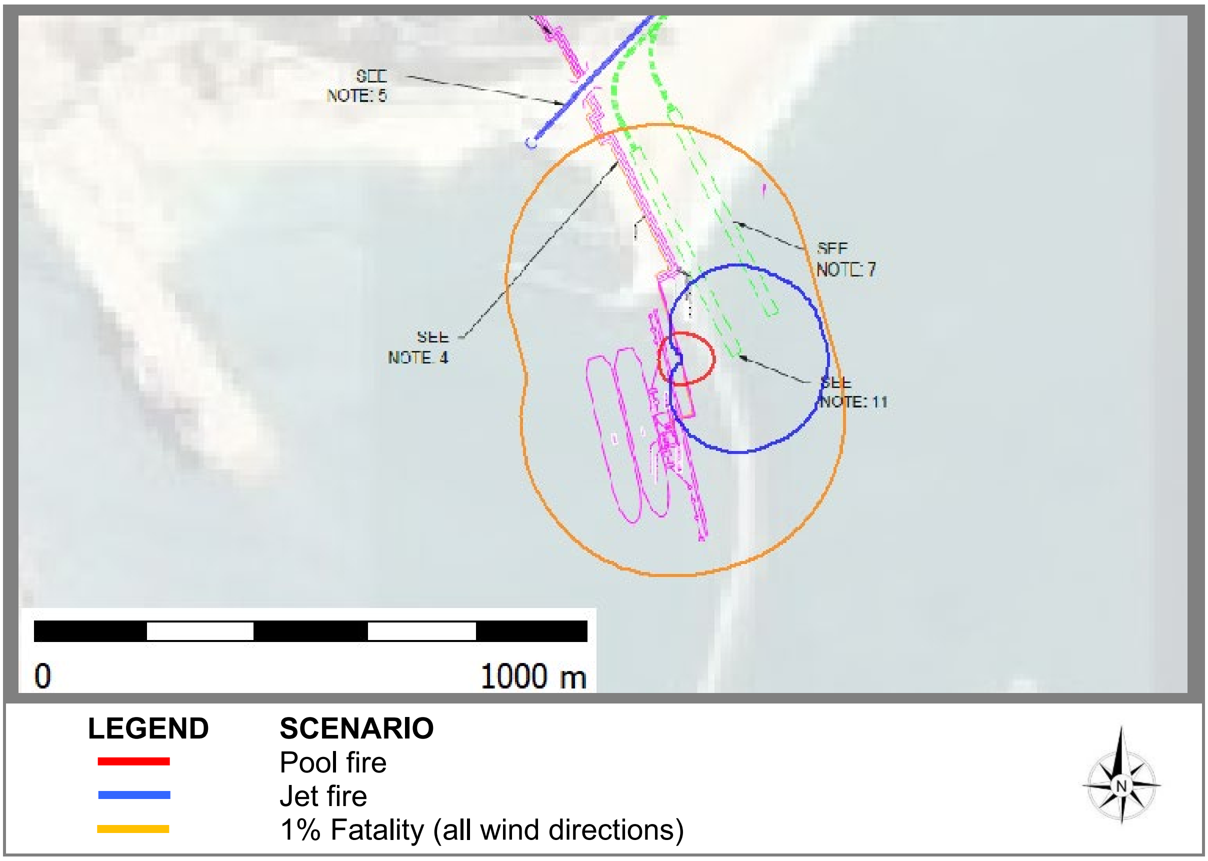


Figure 5-14: The maximum extent of fires and explosions, to the 1% fatality, resulting from a large release from the above ground section of the pipeline

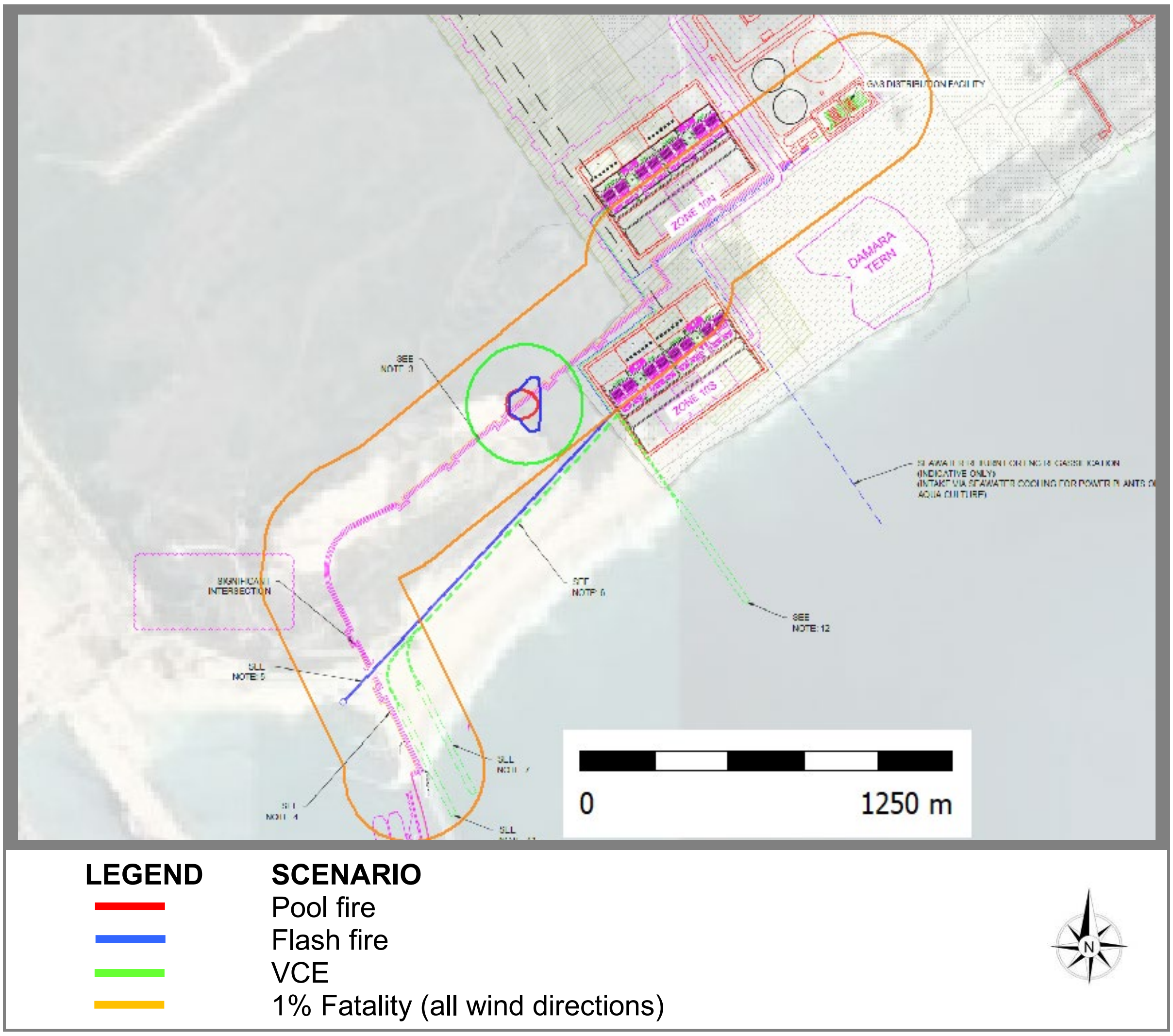


Figure 5-15: The maximum extent of fires and explosions, to the 1% fatality, resulting from a large release from below ground section of the pipeline

5.2.5 Compressed Natural Gas (CNG) Pipeline

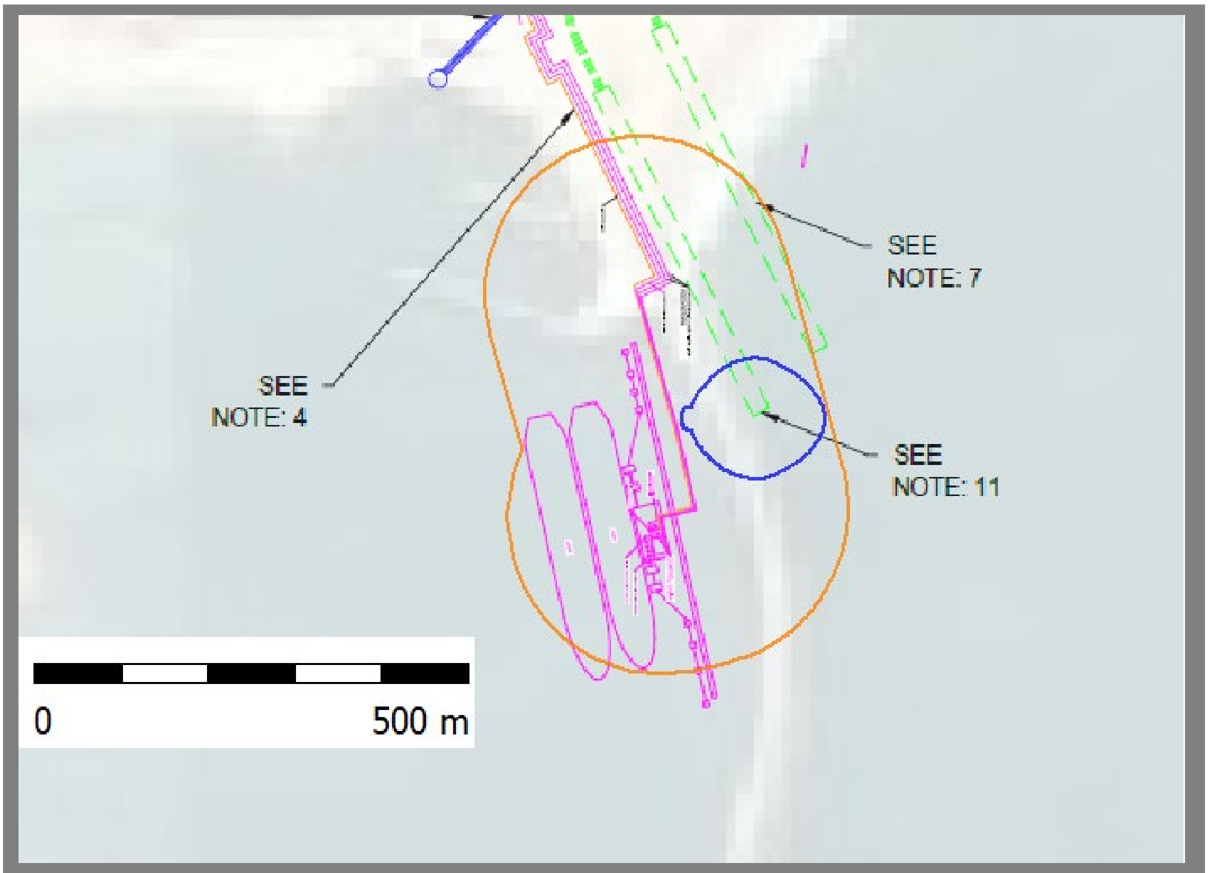
CNG from the FSRU would be sent to the power plants. Initially the pipeline would be above ground to the end of the jetty and then travel underground to the power plants.

For this study the following as assumed:

1. The pipeline: 60 bar
2. Operating temperature: 0ºC
3. Pipeline diameter: 24” NB
4. Flow rate: 8510 m^3/h at operating conditions
5. Release orientation of above ground pipeline: horizontal
6. Release orientation of below ground pipeline: vertical

In accordance with the IGEM/TD/2 and PD 8010-3 standard, the belowground pipeline develops a fireball with a crater and then followed by a jet fire.

The maximum extent to the 1 % fatality for the above and below ground pipelines are given in Figure 5-16. The maximum distances occur at a low wind speed for the horizontal release from an above ground pipeline.



LEGEND	SCENARIO
(blue line)	Jet fire
(yellow line)	1% Fatality (all wind directions)

Figure 5-16: The maximum extent of jet fires, to the 1% fatality, resulting from a large release from the above ground section of the pipeline

For the below ground pipeline, the release is assumed to be horizontal, the initial release would be a fireball followed by a jet fire. The greatest extent will be due to a jet fire at a high windspeed, as shown in Figure 5-17 and could extend 61 m downwind from the release.

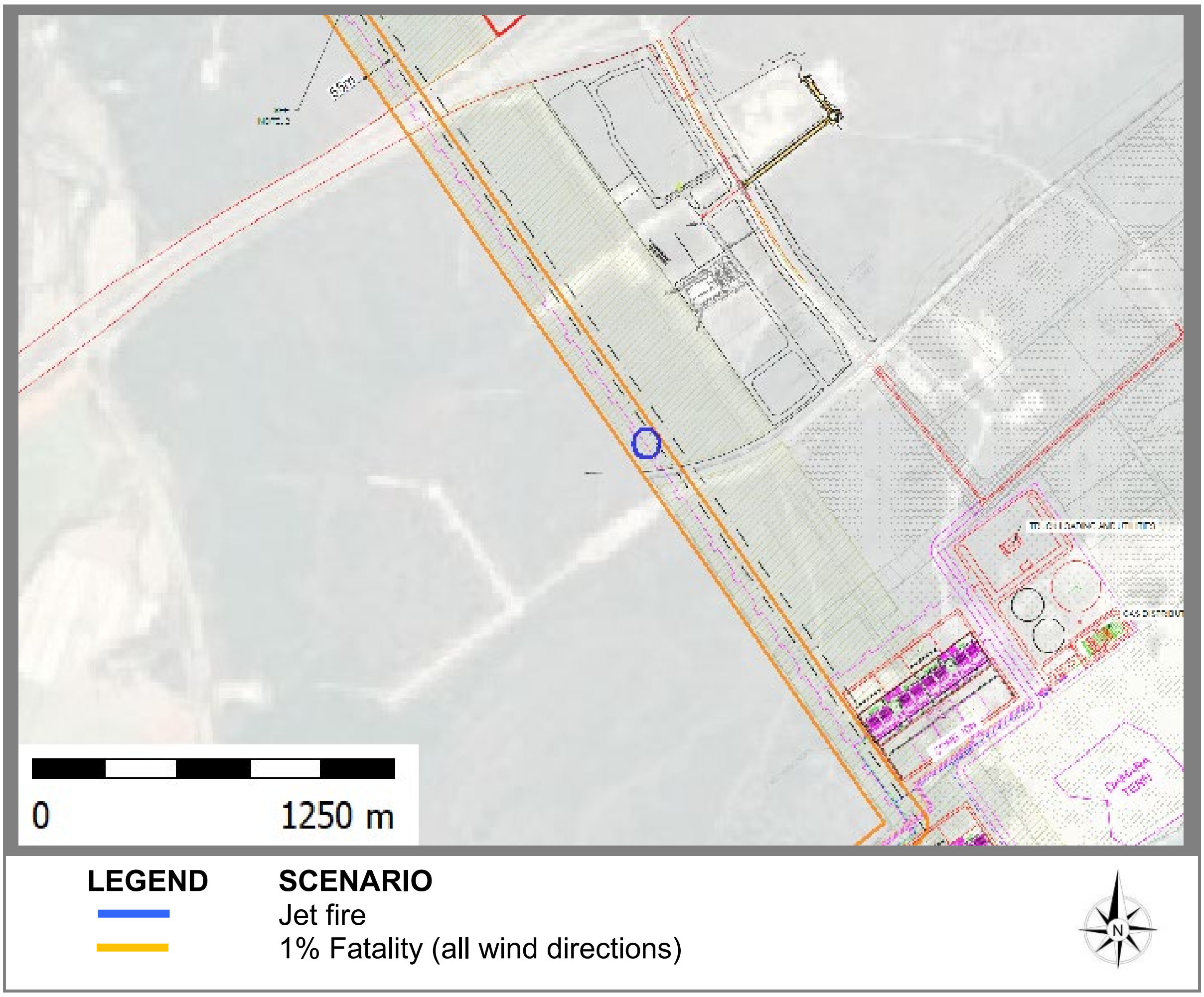


Figure 5-17: The maximum extent of fires and explosions, to the 1% fatality, resulting from a large release from below ground section of the pipeline

5.2.6 Gas distribution Facility

- **LNG Storage**

Phase 2 will include 2 x 160 000 m^3 LNG tanks. For this study, the spilt area was limited to 50 000 m^3. The maximum extent to the 1% fatality from a large release at the LNG storage is shown in Figure 5-18 and can extend to a maximum of 2614 m downwind of the release from a low windspeed. Higher wind speeds result in a considerably reduced endpoint.

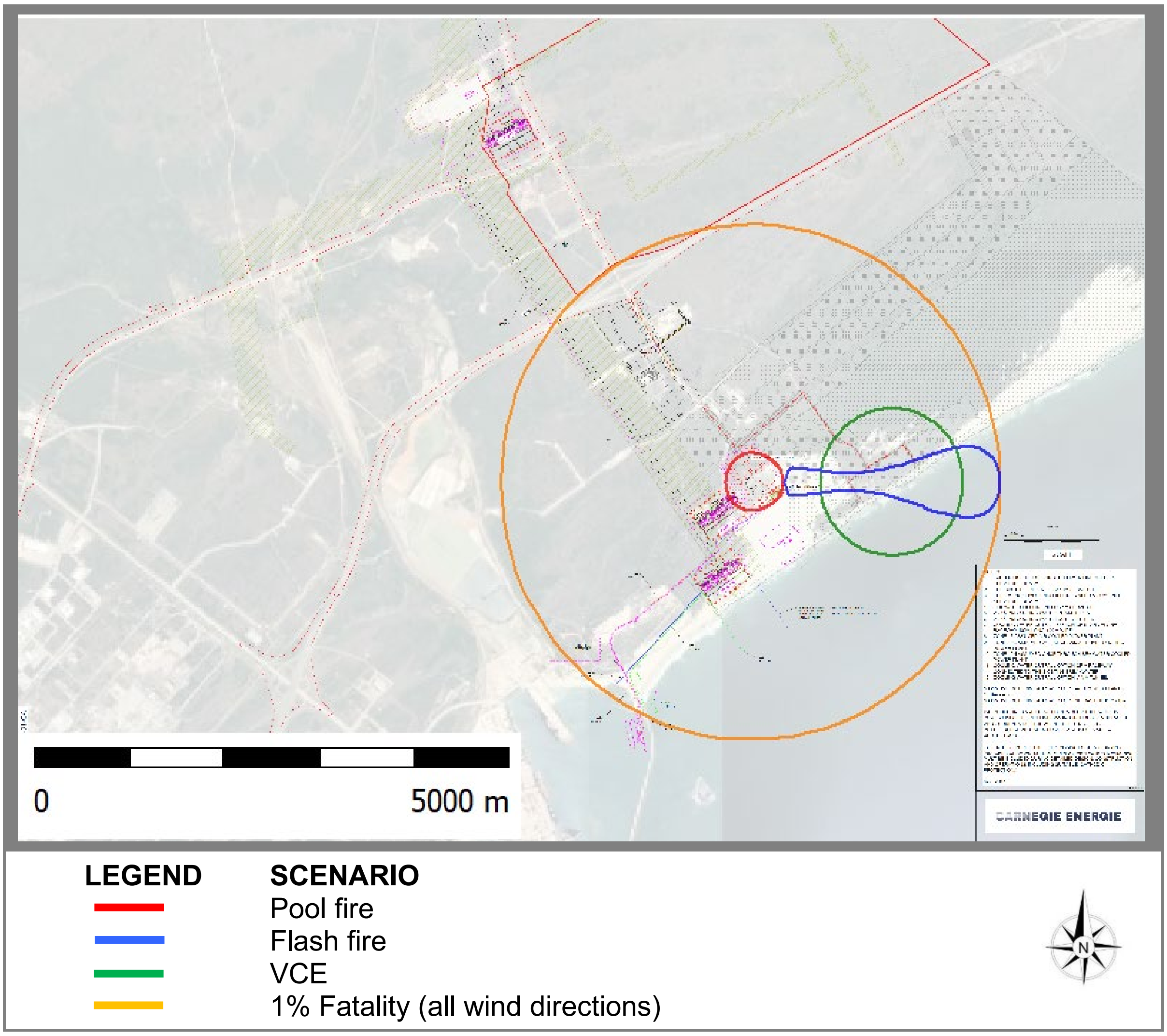


Figure 5-18: The maximum extent of fires and explosions, to the 1% fatality, resulting from a large release at the LNG storage

- **LNG Road Loading**

The LNG would be used to fill road tankers in two loading bays. A maximum of 40 x 20 t tankers would be loaded per day from two loading bays.

The maximum extent from a loss of containment at the road loading bay. The study assumed the maximum extent for the LNG spreading was capped at 1200 m^2. The maximum extent to the 1% fatality, from a large release with an ignition source is shown in Figure 5-19. In this instance, the largest downward distance was due from the catastrophic failure from a road tanker, at a low wind speed. At higher wind speeds, the downward distance decreases considerably.

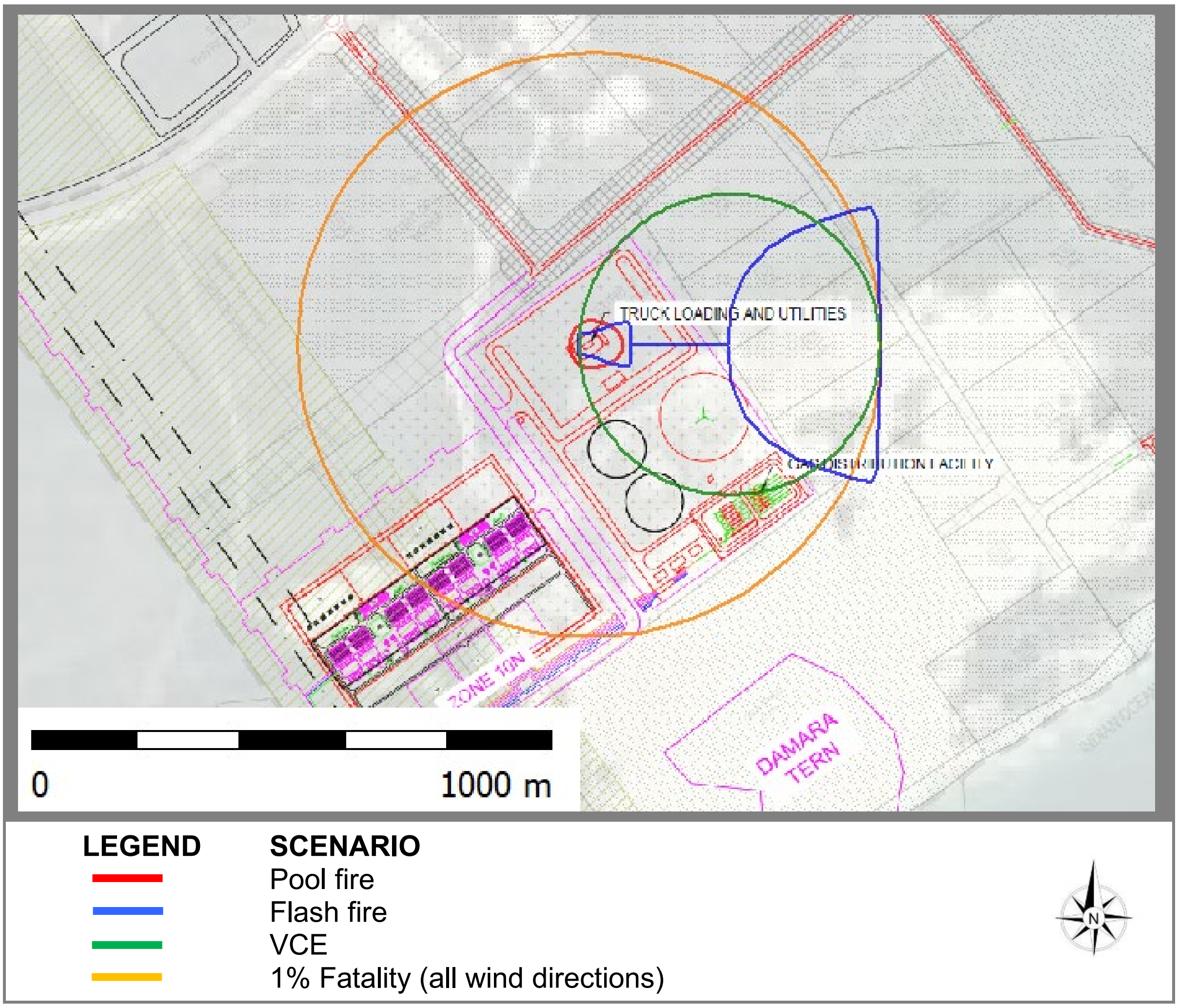


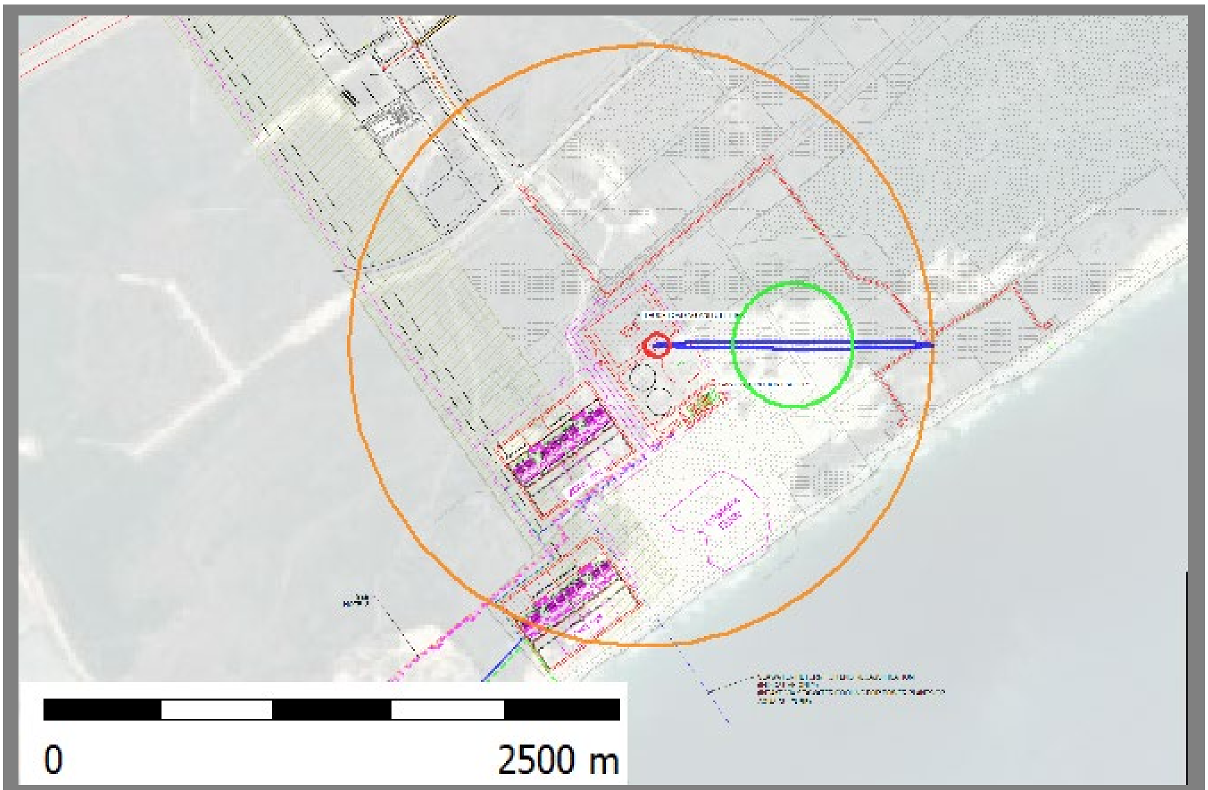
Figure 5-19: The maximum extent of fires and explosions, to the 1% fatality, resulting from a large release at the LNG road gantry

- **Regasification & Compressor**

The regasification and compressor assume two identical units having a 50% capacity each. The regasification would increase and compressor would send CNG into the pipeline at 0°C and 60 bar.

The maximum extent from fires and explosions from failure of the compressor discharge is shown in Figure 5-20. The downward distance is shown from a westerly wind, with the orange curve indicating the largest 1% endpoint from all wind directions.

The maximum distance from this scenario is the turbulent free jet at a low windspeed extending 1262 m from the release. The jet is narrow and thus impacts from this jet will be limited to the immediate area of the jet.



LEGEND	SCENARIO
Red line	Jet fire
Blue line	Flash fire
Green line	VCE
Orange line	1% Fatality (all wind directions)

Figure 5-20: The maximum extent of fires and explosions, to the 1% fatality, resulting from a large release from the regasification and compressor at the gas distribution facility

5.2.6.1 Summary of Impacts

Maximum distances from the point of release to the 1% fatality are summarised for each scenario in Table 5-4.

Table 5-4: Maximum distance to 1% fatality from the point of release

Scenarios	Max. Distance to 1% Fatality (m)
FSRU Collision	
LNG Gantry	
LNG Tanker - Catastrophic failure	601
LNG Tanker - Leak via largest nozzle	83
LNG Tanker hose failure - Failure	81
LPG Tanker hose - Leak	5
Pipeline gantry -Pipeline failure	205
Pipeline gantry -Pipeline leak	118
LNG Storage	
LNG Storge – Catastrophic failure	2614
LNG Storage - Fixed Duration Release Set	365
LNG Storage - Overfill Set	74
Pipeline - CNG above Ground	
Local cloud fire	50
Pipeline failure	176
Pipeline leak	61
Pipeline - CNG below ground	
Local cloud fire	50
Pipeline failure	61
Pipeline leak	36
Pipeline - LNG below ground	
Pipeline failure	105
Pipeline leak	52

Pipeline - LNG above ground	
Pipeline failure	328
Pipeline leak	128
Ship Collision	
Ship Collision	205
Ship Offloading Hose	
Ship transfer hose- Full bore hole	309
Ship transfer hose- Leak	106

5.2.7 Maximum Individual Risk

5.2.7.1 Jetty Operations

The risk isopleths for the jetty operations are shown in Figure 5-21. The risks of 1 x 10^{-4} fatalities per person per year would be unacceptable to the general public and was not reached. The risks are lower than the scenario with the FSRU, even though the risks for the FSRU were generally considered acceptable.

As this isopleth is far from the site boundary, the risks to the general public would be acceptable.

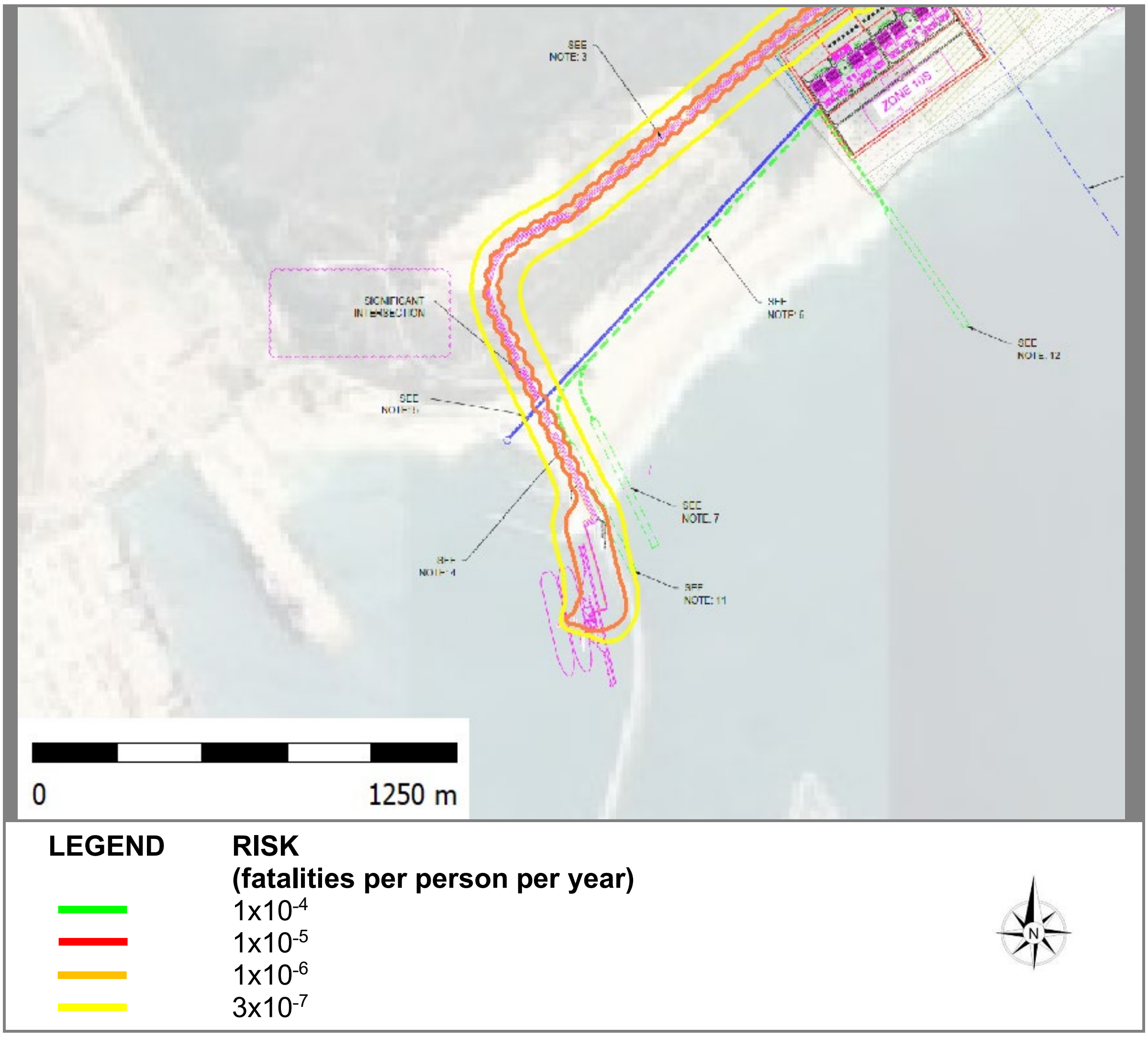


Figure 5-21: Risk isopleths for the jetty operations

5.2.7.2 Gas Distribution Facility

The gas distribution facility receives the LNG from LNG carrier and stores the material in two large storage vessels. The LNG from the storage is used to fill road tankers and is also regasified and transported to the power stations.

The risk isopleths for the gas distribution facility are shown in Figure 5-22. The risks of 1 x 10^{-4} fatalities per person per year would be unacceptable to the general public and remains with in the gas distribution facility. The risks of 1 x 10^{-4} fatalities per person per year would classify the facility as a Major Hazard Installation (MHI) if it impacts both the workers and the public. As the general public are outside of the Coega SEZ, the gas distribution facility **would not be classified as a Major Hazard Installation.**

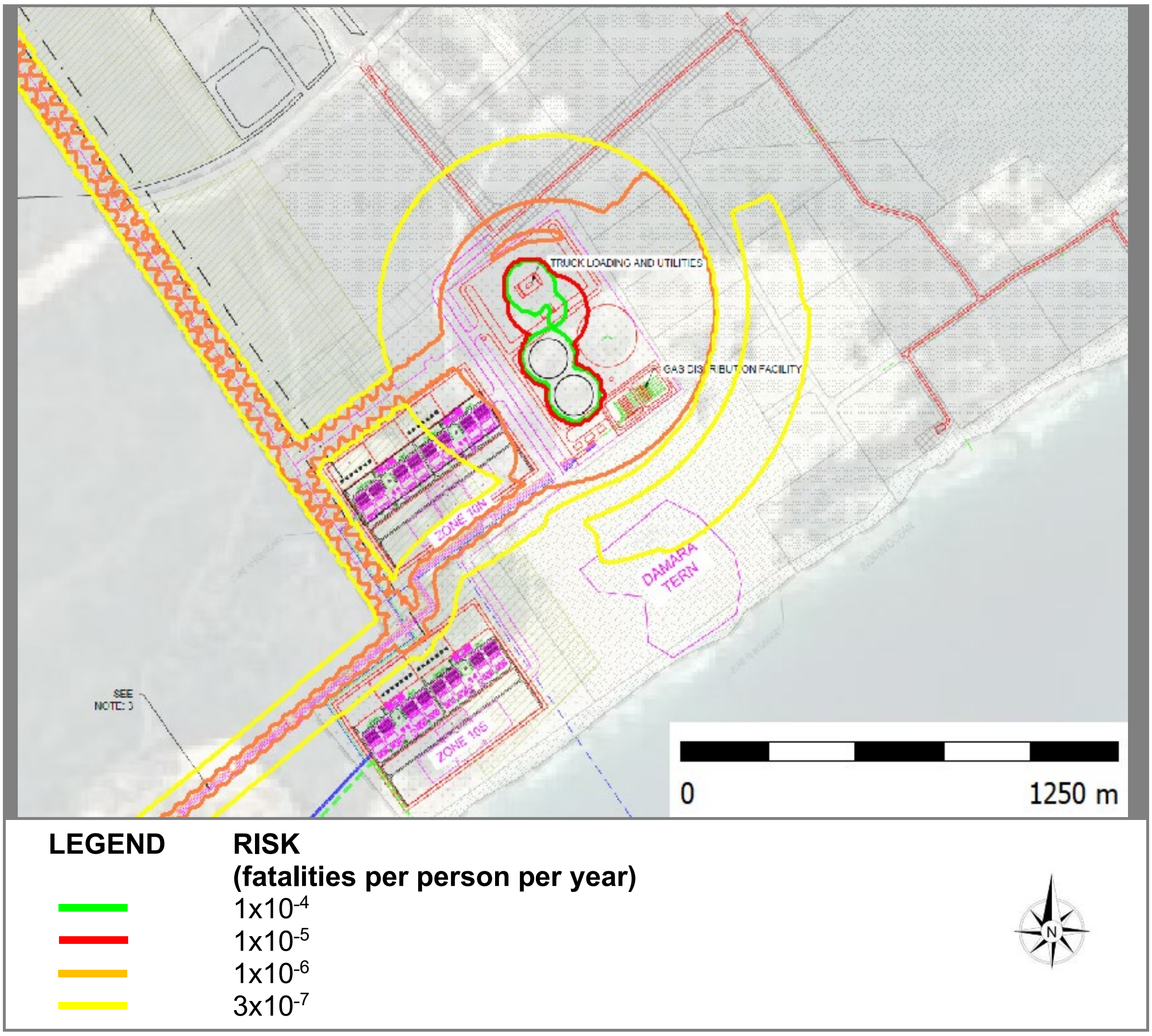


Figure 5-22: Risk isopleths for the LNG road loading operations

5.2.7.3 Pipeline Risks

The pipelines cover both the LNG and CNG pipelines. The jetty section has above ground pipelines with the remaining pipelines being underground. The combined pipeline risks are shown in Figure 5-23.

Risks greater than $1x10^{-4}$ fatalities per person per year, considered tolerable for industrial areas but excessive for the general public and residential areas, were not reached. Thus, the pipeline was not found to be unacceptable.

The risk of $1x10^{-6}$ fatalities per person per year isopleth extends to a maximum of 46 m from the pipeline and remains within the Coega SEZ, having limited impacts onto neighbouring facilities and the general public outside of the Coega SEZ. Thus, the LNG and CNG pipelines **would not be classified as a Major Hazard Installation**.

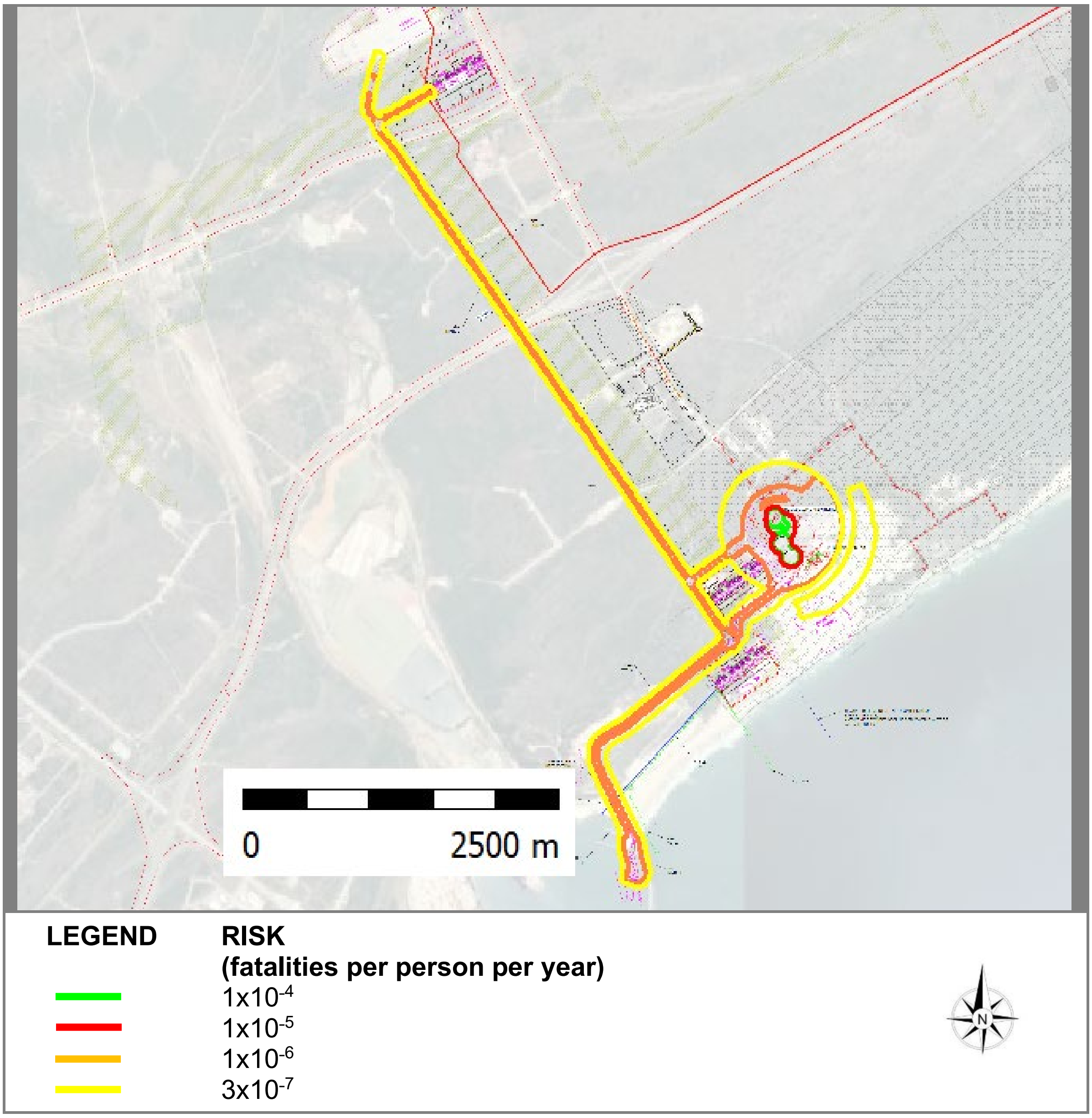


Figure 5-23: Lethal probability isolines associated with the LNG and CNG pipelines

5.3 Consolidated Risks

The proposed LNG gas infrastructure and power plants within the Coega SEZ are shown in Figure 5-24. These impacts described in this report are specific to the proposed gas distribution from the port of Port of Ngqura to the power plants via cryogenic or compressed natural pipeline.

The LNG projects for the power plants shown in Figure 5-24 and consist of the following:

- LNG gas infrastructure;
- Power plant in Zone 10 South;
- Power plant in Zone 10 North;
- Plant plants as part of Zone 13 (including the Mulilo Total power station; and,
- Engie Power Plant in Zone 13

The proposed KarPower installation will consist of up to two power ships moored in the Port of Ngqura. A FSRU will be associated with the power ships to provide the fuel. An LNG carrier will replenish the FSRU fuel on a regular basis. The electricity generated will be sent to the Dedisa substation connecting the national grid.

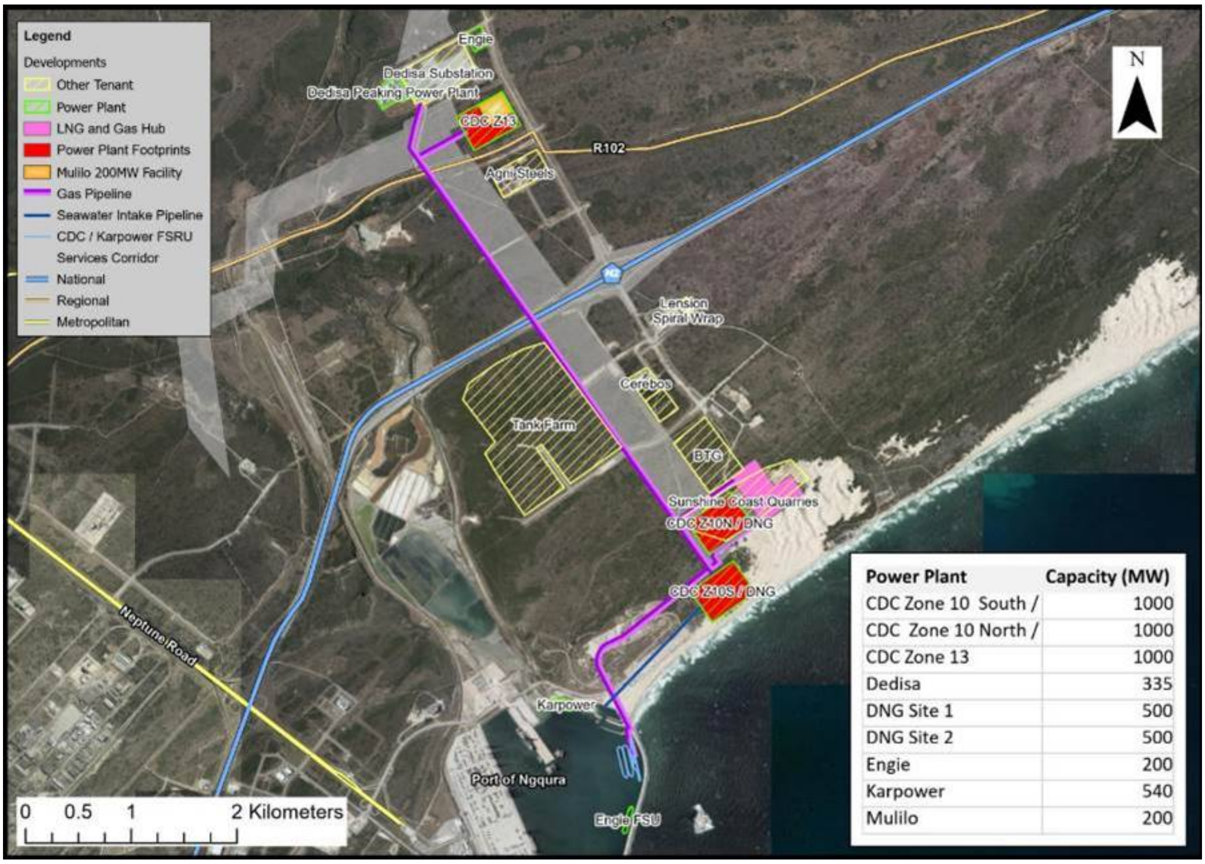


Figure 5-24: Site locality map for the existing developments in the area and proposed gas to power projects in the Coega SEZ (courtesy SRK)

The existing Dedisa Peaking Power Plant operates on diesel fuel[1]. While diesel can burn, the impacts of fires will be limited to the immediate vicinity of the installation.

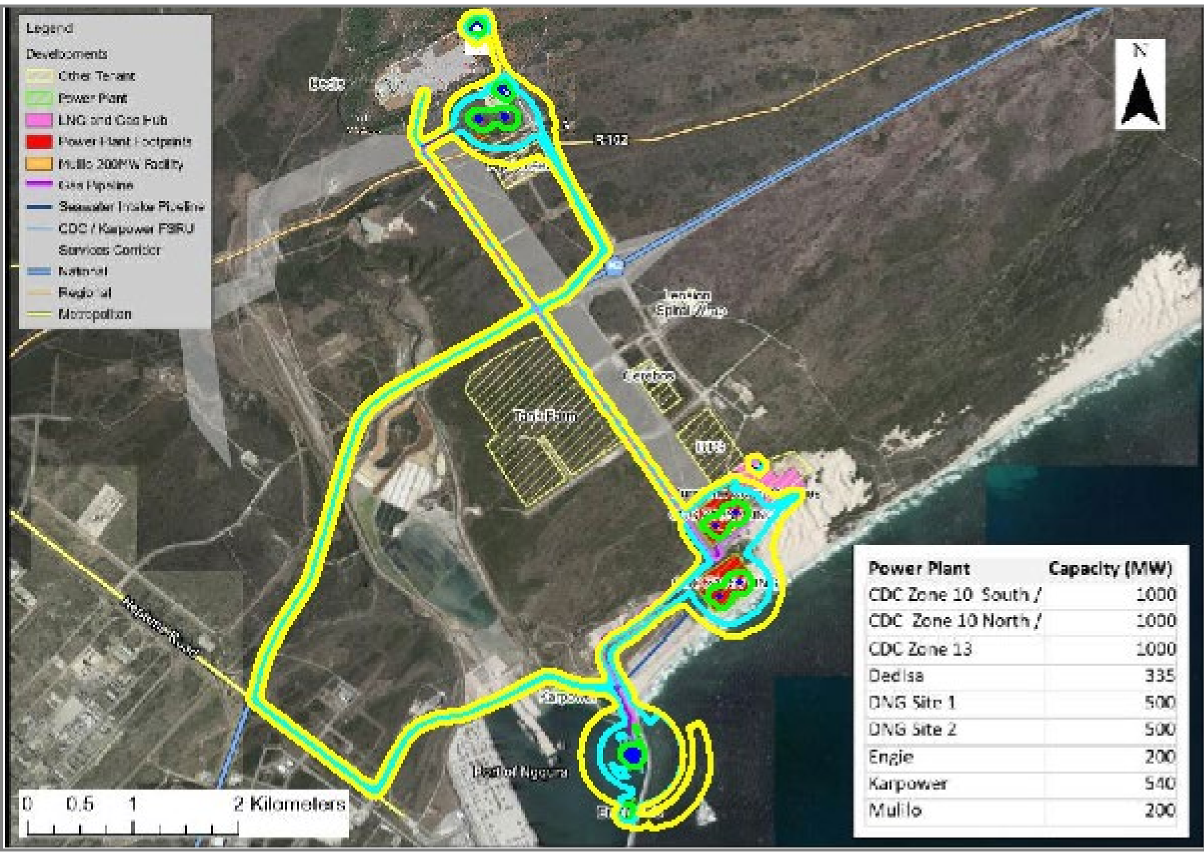
1 It is noted that a proposal to convert the Dedisa Peaking Power Plant to gas has been contemplated. However, the details of this proposal are unknown to the author.

The impacts from the KarPower power plant have been qualitatively assessed[1], resulting in no significant onshore consequences.

All four proposed power plant have been quantitatively assessed for impacts from fires and explosions. The consolidated risks for the power plants and gas distribution for the Phase 1 and Phase 2 of the CDC's gas distribution infrastructure projects are given in Figure 5-25 and Figure 5-26.

The Phase 1 of the project is the importation of LNG via a carrier and will store LNG in the FRU. LNG from the FRU will be used to fuel the Zone 10 and Zone 13 power plants. However, the Engie and Mulilo power plants will use road tankers to deliver LNG to site, where thy will be stored in large tanks.

The risks for the Phase 1, is shown in Figure 5-25. Here the operating risks would remain within the Coega SEZ, except for some road transportation that would exit the Coega SEZ onto the N2 and then re-enters the Coega SEZ. The transportation risks are sufficiently low to the public and would be considered acceptable.



LEGEND	RISK (fatalities per person per year)
(dark blue line)	$1x10^{-4}$
(green line)	$1x10^{-5}$
(cyan line)	$1x10^{-6}$
(yellow line)	$3x10^{-7}$

Figure 5-25: Lethal probability isolines associated for the Coega SEZ Phase 1 of the gas distribution projects

1 NADASEN, N, DAYA, J AND HOOSEN, Z (2020).

While risks were developed for the LNG carriers and FRU, one should be cautious in interpreting these for decision making. The risk used in this assessment are were based on assumptions and not from a marine transportation risk assessment, taking into account marine conditions, number and type of port vessels, international standards and requirements. This risk assessment did not find the risks unacceptable from the suggested LNG vessels in port. However, a more detailed marine risk assessment specific to the LNG within the Port of Ngqura, should be conducted to confirm the acceptability of LNG ships at the positions suggested.

Phase 2 of the gas distribution project essentially moves the LNG storage from the FSU to the onshore storage, that will supply the power stations with LNG It is anticipated that the road transportation of LNG will stop after completion of stage 2.Thus, the risks for Phase 2 increases around the onshore storage after Phase 2.

Phase 2 of the CDC gas infrastructure projects would use the centralised LNG importation from the harbour and the onshore LNG. Road transportation to deliver LNG would not be required. The consolidated risks for the Phase 2 of the power plants is shown in Figure 5-26. Here, the risk from road transportation will diminish and the risk for the storage area will increase. All risks will remain within the Coega SEZ, and thus the risk to the public, located outside of the Coega SEZ will be considered acceptable.

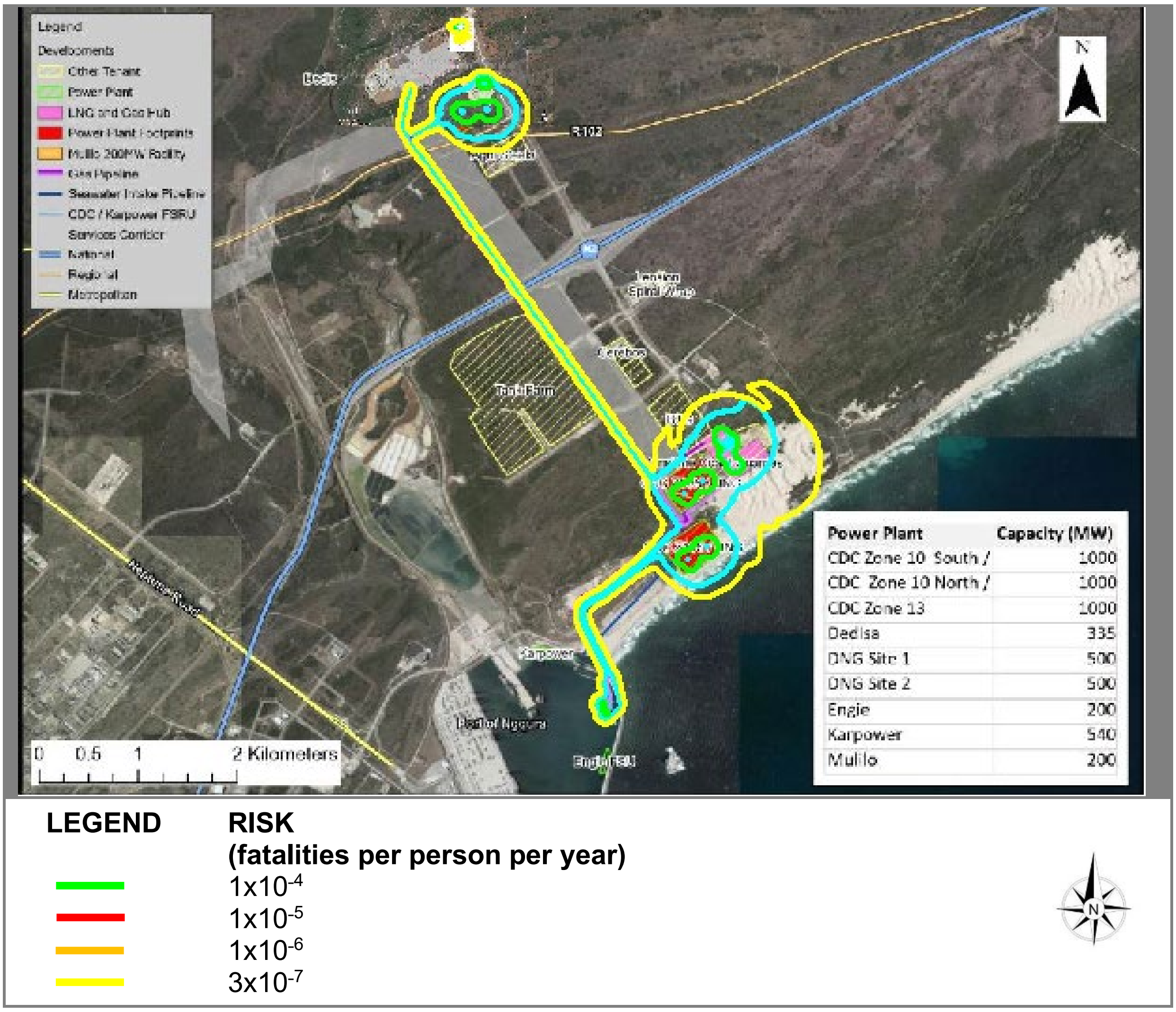


Figure 5-26: Lethal probability isolines associated for the Coega SEZ Phase 2 of the gas distribution and power plants projects

6 RISK REDUCTION

From the simulations performed, the areas of highest risk have been identified as the release of chlorine at various process units.

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.

6.1 Mitigation

6.1.1 Process Hazard Analysis (PHA)

Hazardous areas should be reviewed using detailed Process Hazard Analysis (PHA)[1] such as a HAZOP study. This should be completed to identify potential hazards, and suggest further mitigation for safer operations. Due to the seriousness of the hazardous material stored, transported and produced on site, it is suggested that a detailed PHA/HAZOP study be completed by an independent chairman, who is registered with the Engineering Council of South Africa. Furthermore, any instrument used should incorporate the findings of a SIL assessment defined in IEC 61511.

6.1.2 Codes and Standards

Applicable legal and international best practice LNG and compressed gas transportation and storage and guidelines, or equivalent international recognised codes of good design and practice must be incorporated in the designs. This implies that best practices would be applied to the design and operation of the proposed plants.

6.1.3 Safety Instrumented Systems

IEC 61508/61511 (Safety Instrumented Systems) are codes specifically related to the instrumentation requirements for adequate protection from hazards in chemical plants, and are applicable for the life cycle of the plant. These codes are aimed at reducing risks to surrounding populations to acceptable levels.

The significance of these codes is that the designs would be evaluated against the criteria of the code, and instrumentation with specific failure rates would be specified as well as the minimum periods of checking. Thus, the selection of instrumentation is not based on price alone. Further to this, instrumentation cannot be reduced or changed without reviewing the code. The specification of this code implies that designs presented at EIA and MHI evaluation stages cannot be altered at construction for the sole function of reducing costs. Moreover, the code ensures that the plant would continue to maintain the safety functions for

1 A Process Hazard Analysis is not a regulated activity but mealy identifies potential hazards and recommends mitigation

the *life cycle* of the plant, retaining a safe working environment for both workers and the public.

The European standards body, CENELEC, has adopted the standard as EN 61511. This means that in each of the member states of the European Union, the standard is published as a national standard. For example, in Great Britain, it is published by the national standards body, BSI, as BS EN 61511. The content of these national publications is identical to that of IEC 61511. Note, however, that 61511 is not harmonized under any directive of the European Commission.

In the United States ANSI/ISA 84.00.01-2004 was issued in September 2004. It primarily mirrors IEC 61511 in content with the exception that it contains a grandfathering clause:

Compliance with IEC 61508 and 61511 (or ANSI/ISA 84.00.01-2004) would be a requirement in many countries around the world to achieve an acceptable risk to workers and public.

Demonstrating compliance with the IEC61508/11 can be achieved only once full-detail designs have been completed, and is thus premature at this stage in the project.

It should be noted that RISCOM would require a FULL compliance of the IEC61508/11, with a full audit by an independent body, in order to support the project.

6.1.3.1 Automated Shut-Down System

One of the major contributors towards the high risk at the facility is loss of containment of LNG and natural from pipelines and hoses, that could extend considerable distances from the release. These facilities have not been designed in detail, which allows optimisation of the layout instrumentation and controls.

The control system must be designed to recognise process parameter outside of the normal control and take appropriate actions to either correct the situation or shut down the process safely e.g., the level in the storage tanks should be monitored and would prevent additional product into the tank of a high level to prevent overfilling of the tank.

Additional instrumentation and control must be provided to detect any leak / loss of containment and automatically shut down the system in a safe manner. This is referred to as an Emergency Shut- Down (ESD).

7 IMPACT ASSESSMENT

7.1 Impact Rating Methodology

The assessment of impacts will be based on the professional judgement of specialists at SRK Consulting according to the SRK impact assessment methodology presented below. The impact ratings will be informed by the findings of specialist assessments conducted, fieldwork, and desk-top analysis. The significance of potential impacts that may result from the proposed development will be determined in order to assist DEFF in making a decision.

The significance of an impact is defined as a combination of the consequence of the impact occurring and the probability that the impact will occur. The criteria that are used to determine impact consequences are presented in Table 7-1

Table 7-1: Criteria used to determine the Consequence of the Impact

Rating	Definition of Rating	Score
A. Extent– the area over which the impact will be experienced		
None		0
Local	Confined to project or study area or part thereof (e.g. site)	1
Regional	The region, which may be defined in various ways, e.g. cadastral, catchment, topographic	2
(Inter) national	Nationally or beyond	3
B. Intensity– the magnitude of the impact in relation to the sensitivity of the receiving environment, taking into account the degree to which the impact may cause irreplaceable loss of resources		
None		0
Low	Site-specific and wider natural and/or social functions and processes are negligibly altered	1
Medium	Site-specific and wider natural and/or social functions and processes continue albeit in a modified way	2
High	Site-specific and wider natural and/or social functions or processes are severely altered	3
C. Duration– the time frame for which the impact will be experienced and its reversibility		
None		0
Short-term	Up to 2 years	1
Medium-	2 to 15 years	2
Long-term	More than 15 years	3

The combined score of these three criteria corresponds to a Consequence Rating, as per Table 7-2.

Table 7-2: Method used to determine the Consequence Score

Combined Score (A+B+C)	0 – 2	3 – 4	5	6	7	8 – 9
Consequence Rating	Not significant	Very low	Low	Medium	High	Very high

Once the consequence has been derived, the probability of the impact occurring will be considered using the probability classifications presented in.

Table 7-3: Probability Classification

Probability– the likelihood of the impact occurring	
Improbable	< 40% chance of occurring
Possible	40% - 70% chance of occurring
Probable	> 70% - 90% chance of occurring
Definite	> 90% chance of occurring

The overall significance of impacts will be determined by considering consequence and probability using the rating system prescribed in the table below.

Table 7-4: Impact Significance Ratings

		Probability			
		Improbable	Possible	Probable	Definite
Consequence	Very Low	**INSIGNIFICANT**	**INSIGNIFICANT**	**VERY LOW**	**VERY LOW**
	Low	**VERY LOW**	**VERY LOW**	**LOW**	**LOW**
	Medium	**LOW**	**LOW**	**MEDIUM**	**MEDIUM**
	High	**MEDIUM**	**MEDIUM**	**HIGH**	**HIGH**
	Very High	**HIGH**	**HIGH**	**VERY HIGH**	**VERY HIGH**

Finally, the impacts will also be considered in terms of their status (positive or negative impact) and the confidence in the ascribed impact significance rating. The system for considering impact status and confidence (in assessment) is laid out in the table below.

Table 7-5: Impact status and confidence classification

Status of impact	
Indication whether the impact is adverse (negative) or beneficial (positive).	+ ve (positive – a 'benefit')
	– ve (negative – a 'cost')

Confidence of assessment	
The degree of confidence in predictions based on available information, SRK's judgment and/or specialist knowledge.	Low
	Medium
	High

The impact significance rating should be considered by authorities in their decision-making process based on the implications of ratings ascribed below:

- **Insignificant:** the potential impact is negligible and will not have an influence on the decision regarding the proposed activity/development.
- **Very Low**: the potential impact is very small and should not have any meaningful influence on the decision regarding the proposed activity/development.
- **Low**: the potential impact may not have any meaningful influence on the decision regarding the proposed activity/development.
- **Medium**: the potential impact should influence the decision regarding the proposed activity/development.

- **High**: the potential impact will affect the decision regarding the proposed activity/development.
- **Very High**: The proposed activity should only be approved under special circumstances.

Practicable mitigation measures will be recommended and impacts will be rated in the prescribed way both with and without the assumed effective implementation of mitigation measures. Mitigation measures will be classified as either:

- Essential: must be implemented and are non-negotiable; or
- Optional: must be shown to have been considered, and sound reasons provided by the proponent, if not implemented.

7.2 Assessment of Potential Incidents

The potential assessments for the Phase 1 are given in Table 7-6.

Table 7-6: Assessment of potential incidents

Scenario	Mitigation	Impact description	Extent	Intensity	Duration	Consequence Rating	Probability	Significance	Impact	Confidence
			A	B	C	(A+B+C)				
LNG Carrier – Loss of containment	None	Loss of containment resulting in fires and explosions	1- Local	3-High - due to fatalities	3- Long term - due to fatalities	7 - High	Improbable[1]	MEDIUM	- ve	Medium
	Instrumentation including detection and emergency Shut down	Loss of containment resulting in fires and explosions	1- Local	3-High - due to fatalities	3- Long term - due to fatalities	7 - High	Improbable	MEDIUM	- ve	Medium
FSU – Loss of containment	None	Loss of containment resulting in fires and explosions	1- Local	3-High - due to fatalities	3- Long term - due to fatalities	7 - High	Improbable	MEDIUM	- ve	Medium
	Instrumentation including detection and emergency Shut down	Loss of containment resulting in fires and explosions	1- Local	3-High - due to fatalities	3- Long term - due to fatalities	7 - High	Improbable	MEDIUM	- ve	Medium
Regasification and Compression - Failure	None	Loss of containment resulting in fires and explosions	1- Local	3-High - due to fatalities	3- Long term - due to fatalities	7 - High	Improbable	MEDIUM	- ve	Medium
	Instrumentation including detection and emergency Shut down	Loss of containment resulting in fires and explosions	1- Local	3-High - due to fatalities	3- Long term - due to fatalities	7 - High	Improbable	MEDIUM	- ve	Medium

1. All probabilities will be orders of magnitude lower than the 40% chance for both the mitigate and unmitigated cases.

Scenario	Mitigation	Impact description	Extent	Intensity	Duration	Consequence Rating	Probability	Significance		
			A	B	C	(A+B+C)				
LNG pipeline-Failure	None	Loss of containment resulting in fires and explosions	1- Local	3-High - due to fatalities	3- Long term - due to fatalities	7 - High	Improbable	MEDIUM	- ve	1- Local
	Instrumentation including detection and emergency Shut down	Loss of containment resulting in fires and explosions	1- Local	3-High - due to fatalities	3- Long term - due to fatalities	7 - High	Improbable	MEDIUM	- ve	1- Local
CNG Pipeline Failure	None	Loss of containment resulting in fires and explosions	1- Local	3-High - due to fatalities	3- Long term - due to fatalities	7 - High	Improbable	MEDIUM	- ve	High
	Instrumentation including detection and emergency Shut down	Loss of containment resulting in fires and explosions	1- Local	3-High - due to fatalities	3- Long term - due to fatalities	7 - High	Improbable	MEDIUM	- ve	High
Road loading -Loss of Containment	None	Loss of containment resulting in fires and explosions	1- Local	3-High - due to fatalities	3- Long term - due to fatalities	7 - High	Improbable	MEDIUM	- ve	High
	Instrumentation including detection and emergency Shut down	Loss of containment resulting in fires and explosions	1- Local	3-High - due to fatalities	3- Long term - due to fatalities	7 - High	Improbable	MEDIUM	- ve	High

7.2.1 Assessment of Potential Impacts

The potential assessments for the Phase 2 are given in **Error! Reference source not found.**.

Table 7-7: Assessment of Potential after Phase 2 of the project

Scenario	Mitigation	Impact description	Extent	Intensity	Duration	Consequence Rating	Probability	Significance	Impact	Confidence
			A	B	C	(A+B+C)				
LNG Carrier – Loss of containment	None	Loss of containment resulting in fires and explosions	1- Local	3-High - due to fatalities	3- Long term - due to fatalities	7 - High	Improbable[1]	MEDIUM	- ve	Medium
	Instrumentation including detection and emergency Shut down	Loss of containment resulting in fires and explosions	1- Local	2 -Injury – not necessary fatality	1. Some recovery expected	5 Low	Improbable	VERY LOW	- ve	Medium
Onshore Storage	Standards	Loss of containment resulting in fires and explosions	1- Local	3-High - due to fatalities	3- Long term - due to fatalities	7 - High	Improbable	MEDIUM	- ve	Medium
	Instrumentation including detection and emergency Shut down	Loss of containment resulting in fires and explosions	1- Local	2 -Injury – not necessary fatality	1. Some recovery expected	5 Low	Improbable	VERY LOW	- ve	Medium
Regasification and Compression - Failure	None	Loss of containment resulting in fires and explosions	1- Local	3-High - due to fatalities	3- Long term - due to fatalities	7 - High	Improbable	MEDIUM	- ve	Medium
	Instrumentation including detection and emergency Shut down	Loss of containment resulting in fires and explosions	1- Local	2 -Injury – not necessary fatality	1. Some recovery expected	5 Low	Improbable	VERY LOW	- ve	Medium

1. All probabilities will be orders of magnitude lower than the 40% chance for both the mitigate and unmitigated cases.

Scenario	Mitigation	Impact description	Extent	Intensity	Duration	Consequence Rating	Probability	Significance	Impact	Confidence
			A	B	C	(A+B+C)				
LNG pipeline-Failure	None	Loss of containment resulting in fires and explosions	1- Local	3-High - due to fatalities	3- Long term - due to fatalities	7 - High	Improbable	MEDIUM	- ve	1- Local
	Instrumentation including detection and emergency Shut down	Loss of containment resulting in fires and explosions	1- Local	2 -Injury – not necessary fatality	1. Some recovery expected	5 Low	Improbable	VERY LOW	- ve	1- Local
CNG Pipeline Failure	None	Loss of containment resulting in fires and explosions	1- Local	3-High - due to fatalities	3- Long term - due to fatalities	7 - High	Improbable	MEDIUM	- ve	High
	Instrumentation including detection and emergency Shut down	Loss of containment resulting in fires and explosions	1- Local	2 -Injury – not necessary fatality	1. Some recovery expected	5 Low	Improbable	VERY LOW	- ve	High
Road loading -Loss of Containment	None	Loss of containment resulting in fires and explosions	1- Local	3-High - due to fatalities	3- Long term - due to fatalities	7 - High	Improbable	MEDIUM	- ve	High
	Instrumentation including detection and emergency Shut down	Loss of containment resulting in fires and explosions	1- Local	2 -Injury – not necessary fatality	1. Some recovery expected	5 Low	Improbable	VERY LOW	- ve	High

8 CONCLUSIONS

Risk calculations are not precise. Accuracy of predictions is determined by the quality of base data and expert judgements.

This risk assessment included the consequences of fires and explosions at the CDC facility in the Coega SEZ. A number of well-known sources of incident data were consulted and applied to determine the likelihood of an incident to occur.

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. All designs should be in full compliance with (but not limited to) the Occupational Health and Safety Act 85 of 1993 and its regulations, the National Buildings Regulations and the Buildings Standards Act 107 of 1977 as well as local bylaws.

A number of incident scenarios were simulated, taking into account the prevailing meteorological conditions, and described in the report.

8.1 Notifiable Substances

The General Machinery Regulation 8 and its Schedule A on notifiable substances requires any employer who has a substance equal to or exceeding the quantity listed in the regulation to notify the divisional director. A site is classified as a Major Hazard Installation if it contains one or more notifiable substances or if the off-site risk is sufficiently high. The latter can only be determined from a quantitative risk assessment.

Methane (compressed) is listed as a notifiable substance at a threshold value of 15 t. The schedule does not specifically mention LNG. Furthermore, the storage of LNG would be in the liquid state and not compressed. To this end LNG would not be classified as a notifiable substance.

However, if the design changes so that more than 15 t of CNG would be contained in a single container, the CNG would be classified as a notifiable substance and the facility would automatically be classified as a Major Hazard Installation.

8.2 Phase 1

Phase 1 would consist of an LNG carrier offloading LNG into a Floating Storage and regasification unit (FSRU) From the FSRU, LNG would be transported via a pipeline to the gas distribution facility to load road tankers. Part of the LNG at the FSRU would be regasified into the gas phase and transported to the power stations.

The design has not been completed and thus this design assumed:

- the LNG would be transported in a 24” NB pipeline at 10 bar;
- the compressed natural gas (CNG) would be transported at 0ºC at 60 bar within a 24” NB pipeline.

The potential amount of released material that should be considered as a result of a collision is 126 m^3 in 1800 seconds for a large release (RIVM 2009).

In the worst case, the expected 10 kW/m2 thermal radiation from LNG pool fires on the ocean extend to a maximum distance of 366 m with a full-bore failure of the delivery hose.

An accidental jet fire from the CNG gas pipeline on the ship regasification and compression could have substantial reach and depending on the orientation and point of release. It is assumed that the ship designers would make provision to prevent ship damage from a jet fire.

The release from an LNG pipeline, under low wind speeds could result in significant end point impacts. This is mainly due to the evaporation of cold LNG released onto the ground above the pipeline.

Releases from high pressure CNG pipelines produce a high momentum jet with no significant vapour clouds. Due to the vertical release, the impacts would be limited, with the greatest impact occurring during high wind seeds.

The risks from the Phase 1 will remain within the Port of Ngqura and the Coega SEZ and would not impact the general public outside of this area.

As the cold vent designs have not been completed, the thermal radiation from fires cannot be assessed.

It is common practice to place pipelines within common servitudes. ASME B31.8 Paragraph 841.143 suggests a minimum clearance of a 6” between the pipeline and any other structure.

A literature search did not find any scientific relationship to the minimum distance between adjacent pipelines. Of more importance is the construction and maintenance of such pipelines, bearing in mind that third-party interference resulting in damaged pipelines with injuries and losses is the greatest cause of pipeline failures. For this reason, it is suggested that placing pipelines on top of each other should be avoided and that crossover pipelines be designed and installed with caution.

For new gas transmission pipelines, one should consider a separate adjacent lane with sufficient distance between the lanes for safe construction and maintenance of the pipelines. The distance would be specified by the width of the vehicles involved in such activities.

It is important to note that the maintenance of the pipeline is not limited to construction but also includes inspections. It would be expected that specified vehicles may traverse the length of the transmission pipelines for the observation of leaks or dangers posed to the pipeline. For this reason, an adjacent vehicle lane would be required possibly situated between the gas pipeline and other fuel pipelines.

8.3 Phase 2

The Phase 2 would replace the FSRU with two large storage facilities located at the gas distribution facility. The regasification and unit would also be relocated from the FSRU to the gas distribution centre.

The extent from fires and explosions could extend considerable distances, particularly at low windspeeds. However, the risks from Phase 2 would remain within the Port of Ngqura and the Coega SEZ and would not impact the general public outside of this area. For this reason, the project would not be considered a Major Hazard Installation.

The risks from Phase 2 would result reduces risks at the jetty, but increased risks at the gas distribution centre. It should however be noted that the risks from Phase 1 would not be considered unacceptable.

As the cold vent designs have not been completed, the thermal radiation from fires cannot be assessed.

8.4 Coega SEZ Proposed Power Plant and Gas Distribution Hub Consolidated Risks

The impacts described in this report are specific to the proposed gas distribution from the port of Port of Ngqura to the power plants via cryogenic or compressed natural pipeline.

The four new land-based power plants are shown in have been proposed for the Coega SEZ and consist of the following:

- Power plant in Zone 10 South;
- Power Plant in Zone 10 North;
- Power plant in Zone 13;
- Engie Power Plant; and,
- Gas distribution hub.

The proposed KarPower installation will consist of up to two power ships moored in the Port of Ngqura. A FSRU will be associated with the power ships to provide the fuel. An LNG carrier will replenish the FSRU fuel on a regular basis. The electricity generated will be sent to the Dedisa substation connecting the national grid.

The existing Dedisa Peaking Power Plant operates on diesel fuel. While diesel can burn, the impacts of fires will be limited to the immediate vicinity of the installation.

The impacts from the KarPower power plant have been qualitatively assessed[1], resulting in no significant onshore consequences.

1 NADASEN,N , DAYA, J AND HOOSEN, Z (2020).

The consolidation of the powerplants and gas hub would not significantly change the individual risks of the individual projects, as presented in the various reports. Furthermore, the combined projects risks, would not alter the outcome of the individual site risk, regarding the acceptability or the project related to the public and workers.

8.5 Major Hazard Installation

It should be noted that Section 2 of the MHI regulations applies only if the risk posed by the installation poses a risk to both employees and the public. The definition of an employee under the OHS Act No. 85 of 1993 is that an employee receives remuneration and works under supervision. As all personnel entering the greater complex do so at the access point and have business within the secured boundaries of the complex, such personnel would be considered employees under that definition.

The risk of $1x10^{-6}$ fatalities per person per year isopleth for modelled releases on site does not extend beyond the Coega SEZ boundary. As the general public is located beyond the complex boundary, the proposed operations would not pose a risk to both employees and the public.

This investigation concluded that under the current design conditions the proposed transmission and distribution pipelines would not be considered as a Major Hazard Installation.

This study is not intended to replace the Major Hazard Installation risk assessment which should be completed prior to construction of the terminal.

8.6 Land Planning

In accordance with Section 9 the MHI regulations, no facility within the $3x10^{-7}$ fatalities per person per year isopleths should be approved without first evaluating the impacts on the proposed development or potential land usage. Acceptable developments can be verified in the tables provided in the HSE Land Use Planning Methodology (UK 2011), attached in Appendix D.

9 RECOMMENDATIONS

As a result of the risk assessment study conducted for the proposed CDC facility at the Coega SEZ a number of events were found to have risks beyond the site boundary. These risks could be mitigated to acceptable levels, as shown in the report.

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, i.e., pressure vessel designs;
- Compliance with applicable SANS codes, i.e., SANS 10087, SANS 10089, SANS 10108, etc.;
- Incorporation of applicable guidelines or equivalent international recognised codes of good design and practice into the designs;
- Completion of a recognised process hazard analysis (such as a HAZOP study, FMEA, etc.) on the proposed facility prior to construction to ensure design and operational hazards have been identified and adequate mitigation put in place;
- Full compliance with IEC 61508 and IEC 61511 (Safety Instrument Systems) standards or equivalent to ensure that adequate protective instrumentation is included in the design and would remain valid for the full life cycle of the tank farm:
    - Including demonstration from the designer that sufficient and reliable instrumentation would be specified and installed at the facility;
- Preparation and issue of a safety document detailing safety and design features reducing the impacts from fires, explosions and flammable atmospheres to the MHI assessment body at the time of the MHI assessment:
    - Including compliance to statutory laws, applicable codes and standards and world's best practice;
    - Including the listing of statutory and non-statutory inspections, giving frequency of inspections;
    - Including the auditing of the built facility against the safety document;
    - Noting that codes such as IEC 61511 can be used to achieve these requirements;
- Demonstration by the CDC or their contractor that the final designs would reduce the risks posed by the installation to internationally acceptable guidelines;
- Signature of all terminal designs by a professional engineer registered in South Africa in accordance with the Professional Engineers Act, who takes responsibility for suitable designs;
- Completion of an emergency preparedness and response document for on-site and off-site scenarios prior to initiating the MHI risk assessment (with input from local authorities);
- Permission not being granted for increases to the product list or product inventories without redoing part of or the full EIA;
- Final acceptance of the facility risks with an MHI risk assessment that must be completed in accordance to the MHI regulations, basing such a risk assessment on the final design and including engineering mitigation.

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11 ABBREVIATIONS AND ACRONYMS

AA	See **PADHI**
ACB	**Admin Craft Basin**
AIA	See **Approved Inspection Authority**
ALARP	The UK Health and Safety Executive (HSE) developed the risk **ALARP** triangle, in an attempt to account for risks in a manner similar to those used in everyday life. This involved deciding: • Whether a risk is so high that something must be done about it; • Whether the risk is or has been made so small that no further precautions are necessary; • Whether a risk falls between these two states and has been reduced to levels '**as low as reasonably practicable'** (ALARP). Reasonable practicability involves weighing a risk against the trouble, time and money needed to control it.
API	The **American Petroleum Institute** is the largest U.S. trade association for the oil and natural gas industry. It claims to represent nearly 600 corporations involved in production, refinement, distribution, and many other aspects of the petroleum industry.
Approved Inspection Authority	An **approved inspection authority** (AIA) is defined in the Major Hazard Installation regulations (July 2001)
ASME	The **American Society of Mechanical Engineers** (**ASME**) is an American professional association that, in its own words, "promotes the art, science, and practice of multidisciplinary engineering and allied sciences around the globe" via "continuing education, training and professional development, codes and standards, research, conferences and publications, government relations, and other forms of outreach.
Asphyxiant	An **asphyxiant** is a gas that is nontoxic but may be fatal if it accumulates in a confined space and is breathed at high concentrations since it replaces oxygen containing air.
Blast Overpressure	**Blast overpressure** is a measure used in the multi-energy method to indicate the strength of the blast, indicated by a number ranging from 1 (for very low strengths) up to 10 (for detonative strength).
BLEVE	**Boiling liquid expanding vapour explosions** result from the sudden failure of a vessel containing liquid at a temperature above its boiling point. A **BLEVE** of flammables results in a large fireball.
BoG	**Boil off Gas** Heat slowly affects the tanks, which can cause the LNG inside to evaporate and produces a substance known as **boil-off gas** (BOG). Natural **gas** remains liquefied by staying at a consistent pressure, but when **boil-off** occurs and it returns to **gas**, the larger volume of **gas** will increase the tank pressure.
BS	**British Standards**, also known as the BSI Group, is the national standards body of the United Kingdom. BSI produces technical standards on a wide range of products and services and also supplies certification and standards-related services to businesses.
CDC	The **Coega Development Corporation** (CDC) is the global award-winning public entity that is wholly owned by the Eastern Cape Provincial Government in South Africa.

CNG	**Compressed Natural Gas.** Natural gas at pressure above its critical pressure
DAA	See **PADHI**
Detonation	**Detonation** is a release of energy caused by extremely rapid chemical reaction of a substance, in which the reaction front of a substance is determined by compression beyond the auto-ignition temperature.
EGIG	**European Gas Pipeline Incident Data Group i**s a co-operation between a group of seventeen major gas transmission system operators in Europe to gather data on the unintentional releases of gas in their pipeline transmission systems.
EIA	**Environmental impact assessment** Environmental assessment is the assessment of the environmental consequences of a plan, policy, program, or actual projects prior to the decision to move forward with the proposed action.
Emergency Plan	An **emergency plan** is a plan in writing that describes how potential incidents identified at the installation together with their consequences should be dealt with, both on site and off site.
ESD	**Emergency Shut- Down Emergency Shutdown** (ESD) is designed to minimize the consequences of emergency situations, related to typically uncontrolled flooding, escape of hydrocarbons, or outbreak of fire in hydrocarbon carrying areas or areas which may otherwise be hazardous.
Explosion	An **explosion** is a release of energy that causes a pressure discontinuity or blast wave.
FERC	The **Federal Energy Regulatory Commission** is the United States federal agency that regulates the transmission and wholesale sale of electricity and natural gas in interstate commerce and regulates the transportation of oil by pipeline in interstate commerce.
Flammable Limits	**Flammable limits** are a range of gas or vapour concentrations in the air that will burn or explode if a flame or other ignition source is present. The lower point of the range is called the lower flammable limit (LFL). Likewise, the upper point of the range is called the upper flammable limit (UFL).
Flammable Liquid	The Occupational Health and Safety Act 85 of 1993 defines a **flammable liquid** as any liquid which produces a vapour that forms an explosive mixture with air and includes any liquid with a closed cup flashpoint of less than 55°C. Flammable products have been classified according to their flashpoints and boiling points, which ultimately determine the propensity to ignite. Separation distances described in the various codes are dependent on the flammability classification. **Class Description** 0 Liquefied petroleum gas (LPG) IA Liquids that have a closed cup flashpoint of below 23°C and a boiling point below 35°C IB Liquids that have a closed cup flashpoint of below 23°C and a boiling point of 35°C or above IC Liquids that have a closed cup flashpoint of 23°C and above but below 38°C II Liquids that have a closed cup flashpoint of 38°C and above but below 60.5°C

	IIA Liquids that have a closed cup flashpoint of 60.5°C and above but below 93°C
Flash Fire	A **flash fire** is defined as combustion of a flammable vapour and air mixture in which the flame passes through the mixture at a rate less than sonic velocity so that negligible damaging overpressure is generated.
Frequency	**Frequency** is the number of times an outcome is expected to occur in a given period of time.
FSRU	**Floating Storage Regasification Unit** (FSRU) is a vital component required while transiting and transferring Liquefied Natural Gas (LNG) through the oceanic channels. Therefore, FSRU can be termed as a special type of ship used for LNG transfer.
HAZOP	A **Hazard and operability study** is a structured and systematic examination of a complex planned or existing process or operation in order to identify and evaluate problems that may represent risks to personnel or equipment.
HEL	**Higher Explosive Limits** The maximum concentration of a gas or vapor that will burn in air is defined as the Upper Explosive Limit (UEL). Above this level, the mixture is too “rich” to burn. The range between the LEL and UEL is known as the flammable range for that gas or vapor.
HSE	**Health and Safety Executive** is a UK government agency responsible for the encouragement, regulation and enforcement of workplace health, safety and welfare, and for research into occupational risks in Great Britain.
Ignition Source	An **ignition source** is a source of temperature and energy sufficient to initiate combustion.
Individual Risk	**Individual risk** is the probability that in one year a person will become a victim of an accident if the person remains permanently and unprotected in a certain location. Often the probability of occurrence in one year is replaced by the frequency of occurrence per year.
Isopleth	See **Risk Isopleth**
Jet	A **jet** is the outflow of material emerging from an orifice with significant momentum.
Jet Fire or Flame	A **jet fire or flame** is combusting material emerging from an orifice with a significant momentum.
LEL	**Lower Explosive Limit** usually expressed in volume per cent, is the lower end of the concentration range over which a flammable mixture of gas or vapour in air can be ignited at a given temperature and pressure. The flammability range is delineated by the upper and lower flammability limits.
LFL	**Lower Flammable Limit** see Flammable Limits
LNG	**Liquid Natural Gas.** Natural gas below its boiling point of around -162ºC
LNGC	**Liquefied Natural Gas Carrier** is an LNG carrier tank ship designed for transporting liquefied natural gas (LNG). As the LNG market grows rapidly, the fleet of LNG carriers continues to experience tremendous growth.
LOC	See **Loss of Containment**
LoR	**Loss of Resources**
Local Government	**Local government** is defined in Section 1 of the Local Government Transition Act, 1993 (Act No. 209 of 1993).
Loss of Containment	**Loss of containment** (LOC) is the event resulting in a release of material into the atmosphere.

Major Hazard Installation	**Major Hazard Installation** (MHI) means an installation: • Where more than the prescribed quantity of any substance is or may be kept, whether permanently or temporarily; • Where any substance is produced, used, handled or stored in such a form and quantity that it has the potential to cause a major incident (the potential of which will be determined by the risk assessment).
Major Incident	A **major incident** is an occurrence of catastrophic proportions, resulting from the use of plant or machinery or from activities at a workplace. When the outcome of a risk assessment indicates that there is a possibility that the public will be involved in an incident, then the incident is catastrophic.
Material Safety Data Sheet	According to ISO-11014, a **material safety data sheet** (MSDS) is a document that contains information on the potential health effects of exposure to chemicals or other potentially dangerous substances and on safe working procedures when handling chemical products. It is an essential starting point for the development of a complete health and safety program. It contains hazard evaluations on the use, storage, handling and emergency procedures related to that material. An MSDS contains much more information about the material than the label and it is prepared by the supplier. It is intended to tell what the hazards of the product are, how to use the product safely, what to expect if the recommendations are not followed, what to do if accidents occur, how to recognize symptoms of overexposure and what to do if such incidents occur.
MEGC	**Multiple Element Gas Containers** Multimodal assemblies of cylinders, tubes, and bundles of cylinders, which are interconnected by a manifold and assembled within a framework. The MEGC includes service equipment and structural equipment necessary for the transport of gases.
MHI	See **Major Hazard Installation**
MIR	**Maximum Individual Risk** (see Individual Risk)
MSDS	See **Material Safety Data Sheet**
MW	**Megawatt** is a unit of power equal to one million watts, especially as a measure of the output of a power station.
NB	The **Nominal Bore** is the hollow section of the pipe. **Nominal** refers to the approximate measurement of the **bore**. Pipe was originally measured in inches. 100NB pipe works out to be exactly 4.5 inches (4.5(inches) x 25.4(mm/inch) = 114.3mm). That is why the outside diameter can't be simple number like 100mm.
NEMA	**National Environmental Management Act** 107 of 1998, abbreviated **NEMA**) is the statutory framework to enforce Section 24 of the Constitution of the Republic of **South Africa**. The **NEMA** is intended to promote co-operative governance and ensure that the rights of people are upheld, but also recognising the necessity of economic development.
NG	**Natural Gas** is a naturally occurring hydrocarbon gas mixture consisting primarily of methane, but commonly including varying amounts of other higher alkanes, and sometimes a small percentage of carbon dioxide, nitrogen, hydrogen sulphide, or helium.
NOAA	The **National Oceanic and Atmospheric Administration** is an American scientific agency within the United States Department of Commerce that focuses on the conditions of the oceans, major waterways, and the atmosphere.
OHS Act	**Occupational Health and Safety Act**, 1993 (Act No. 85 of 1993)

ORV	**Open Rack Vaporisers** The open rack type LNG vaporizer (ORV) uses seawater as its heat source and is a typical higher flow LNG vaporizer. The seawater enters the top of the vaporizer and is runs over the aluminium tubes. The LNG flows up and is converts from a liquid into a gas. The benefit of using heat from the seawater is that this energy is for free and there is no further CO_2 emission for regasifying the LNG. The water is gathered in the basin at the bottom of the vaporizer tubes before being returned to the sea.
PADHI	**PADHI** (**planning advice for developments near hazardous installations**) is the name given to a methodology and software decision support tool developed and used in the HSE. It is used to give land-use planning (LUP) advice on proposed developments near hazardous installations. PADHI uses two inputs into a decision matrix to generate either an 'advise against' or 'don't advise against' response: • The zone in which the development is located of the three zones that HSE sets around the major hazard: o The inner zone (> $1x10^{-5}$ fatalities per person per year); o The middle zone ($1x10^{-5}$ fatalities per person per year to $1x10^{-6}$ fatalities per person per year); o The outer zone ($1x10^{-6}$ fatalities per person per year to $3x10^{-7}$ fatalities per person per year); • The 'sensitivity level' of the proposed development which is derived from an HSE categorisation system of 'development types' (see the 'development type tables' in Appendix D).
PER	The **Pressure Equipment Regulations** govern the handling, installation and maintenance of pressure equipment, and requires all businesses in the industry to register employees that handle pressure equipment.
PHA	A **Process Hazard Analysis (**PHA) is directed toward analysing potential causes and consequences of fires, explosions, releases of toxic or flammable chemicals and major spills of hazardous chemicals, and it focuses on equipment, instrumentation, utilities, human actions, and external factors that might impact the process.
POST	**Parliamentary Office of Science and Technology** is the Parliament of the United Kingdom's in-house source of independent, balanced and accessible analysis of public policy issues related to science and technology.
PPE	**Personal protective equipment** is protective clothing, helmets, goggles, or other garments or equipment designed to protect the wearer's body from injury or infection. The hazards addressed by protective equipment include physical, electrical, heat, chemicals, biohazards, and airborne particulate matter.
QRA	See **Quantitative Risk Assessment**
Quantitative Risk Assessment	A **quantitative risk assessment** is the process of hazard identification, followed by a numerical evaluation of effects of incidents, both consequences and probabilities and their combination into the overall measure of risk.
Risk	**Risk** is the measure of the consequence of a hazard and the frequency at which it is likely to occur. Risk is expressed mathematically as: **Risk = Consequence x Frequency of Occurrence**

Risk Assessment	**Risk assessment** is the process of collecting, organising, analysing, interpreting, communicating and implementing information in order to identify the probable frequency, magnitude and nature of any major incident which could occur at a major hazard installation and the measures required to remove, reduce or control potential causes of such an incident.
Risk Contour	See **Risk Isopleth**
SANAS	**South African National Accreditation System.** The South African National Accreditation System (SANAS) is the only national body responsible for carrying out accreditations in respect of conformity assessment, as mandated through the Accreditation for Conformity Assessment, Calibration and Good Laboratory Practice Act (Act 19 of 2006).
SEZ	**Special economic zone** is an area in which the business and trade laws are different from the rest of the country. SEZs are located within a country's national borders, and their aims include increased trade balance, employment, increased investment, job creation and effective administration.
SIL	Within the IEC 61508 / 61511 standards, the **Safety Integrity Level** (**SIL)** is a fundamental means of specifying the safety integrity requirements of a SIF. SIL Determination is an assessment of the risk reduction required from SIFs to give a sufficiently low level of risk in relation to a specific hazardous event.
Societal Risk	**Societal risk** is risk posed on a societal group who are exposed to a hazardous activity.
SST	**sea surface temperature** is the water temperature close to the ocean's surface. The exact meaning of surface varies according to the measurement method used, but it is between 1 millimetre and 20 metres below the sea surface.
Temporary Installation	A **temporary installation** is an installation that can travel independently between planned points of departure and arrival for the purpose of transporting any substance and which is only deemed to be an installation at the points of departure and arrival, respectively.
TETCO	**Texas Eastern Transmission Corporation** operates as an oil and gas company. The Company offers transportation of oil and natural gas products through pipelines.
TNPA	**Transnet National Ports Authority** (TNPA) is a government corporation of South Africa and subsidiary of Transnet, responsible for managing and governing eight of South Africa's major seaports.
tpd	**tons per day**
UEL	**upper explosive limit,** the highest concentration of a gas or vapor (percentage by volume in air) above which a flame will not spread in the presence of an ignition source (arc, flame, or heat). Concentrations higher than UEL are “too rich” to burn.
UFL	**Upper Flammable Limit** (see Flammable Limits)
Vapour Cloud Explosion	A **vapour cloud explosion** (VCE) results from ignition of a premixed cloud of a flammable vapour, gas or spray with air, in which flames accelerate to sufficiently high velocities to produce significant overpressure.
VCE	See **Vapour Cloud Explosion**

12 APPENDIX A: DEPARTMENT OF LABOUR CERTIFICATE

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**

13 APPENDIX B: SANAS CERTIFICATES

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 2118 Issue No.: 12 Date of issue: 28 February 2013 Expiry date: 26 May 2017	
Nominated Representative: Mr M Oberholzer	**Quality Manager:** Mr M Oberholzer **Technical Manager:** Mr M Oberholzer	**Technical Signatory:** Mr M 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

Field Manager

14 APPENDIX C: NOTIFICATION OF MAJOR HAZARD INSTALLATION

Prior to assessment of potential impacts of various accidental spills, reference needs to be made to the legislation, regulations and guidelines governing the operation of the development.

Section 1 of the Occupational Health and Safety Act (OHS Act; Act No. 85 of 1993) defines a "major hazard installation" to mean an installation:

" (a) *Where more than the prescribed quantity of any substance is or may be kept, whether permanently or temporarily;*

(b) *Where any substance is produced, processed, used, handled or stored in such a form and quantity that it has the potential to cause a major incident (our emphasis).* "

It should be noted that if either (a) or (b) is satisfied, the Major Hazard Installation (MHI) regulations will apply. The prescribed quantity of a chemical can be found in Section 8(1) of the General Machinery Regulation 8 (our emphasis).

A major incident is defined as: "an occurrence of catastrophic proportions, resulting from the use of plant and machinery or from activities at a workplace". Catastrophic in this context means loss of life and limbs or severe injury to employees or members of the public, particularly those who are in the immediate vicinity (our emphasis).

It is important to note that the definition refers to an occurrence, whereas Section 1b) refers to potential to cause a major incident. If potential to cause a major incident exists, then the OHS Act and the Major Hazard Installation regulations will apply (our emphasis).

On the 16th of January 1998, the MHI regulations were promulgated under the OHS Act (Act No. 85 of 1993), with a further amendment on the 30th of July 2001. The provisions of the regulations apply to installations that have on their premises a certain quantity of a substance that can pose a significant risk to the health and safety of employees and the public.

The scope of application given in Section 2 of the MHI regulations is as follows:

" (1) *Subject to the provisions of Sub regulation (3) these regulations shall apply to employers, self-employed persons and users, who have on their premises, either permanently or temporarily, a major hazard installation or a quantity of a substance which may pose a risk that could affect the health and safety of employees and the public (our emphasis);*

(2) *These regulations shall apply to local governments, with specific reference to Regulation 9.* "

It is important to note that the regulations refer to a substance, and furthermore the regulations are applicable to risks posed by the substance and **NOT** merely the potential consequences (our emphasis).

The regulations essentially consist of six parts, namely:

1. Duties for notification of a Major Hazard Installation (existing or proposed), including:
    a. Fixed (see List 1);
    b. Temporary installations;
2. Minimum requirements for a quantitative risk assessment (see List 2);
3. Requirements of an on-site emergency plan (see List 3);
4. Reporting steps of risk and emergency occurrences (see List 4);
5. General duties required of suppliers;
6. General duties required of local government.

Notification of installation (List 1) indicates that:

- Applications need to be made in writing to the relevant local authority and the provincial director for permission:
    - To erect any Major Hazard Installation;
    - Prior to the modification of any existing installation that may significantly increase risk related to it (e.g. an increase in storage or production capacity or alteration of a process);
- Applications need to include the following information:
    - The physical address of installation;
    - Complete material safety data sheets of all hazardous substances;
    - The maximum quantity of each substance envisaged to be on premises at any one time;
    - The risk assessment of the installation (see List 2);
    - Any further information that may be deemed necessary by an inspector in interests of health and safety to the public;
- Applications need to be advertised in at least one newspaper serving the surrounding communities and by way of notices posted within these communities.

The risk assessment (List 2):

- Is the process of collecting, organising, analysing, interpreting, communicating and implementing information in order to identify the probable frequency, magnitude and nature of any major incident which could occur at a Major Hazard Installation and measures required to remove, reduce or control the potential causes of such an incident;
- Needs to be undertaken at intervals not exceeding 5 years and needs to be submitted to the relevant local emergency services;
- Must be made available in copies to the relevant health and safety committee, with 60 days given to comment thereon and the results of the assessment made available to any relevant representative or committee to comment thereon;
- Should be undertaken by competent person(s) and include the following:
  - A general process description;
  - A description of major incidents associated with this type of installation and consequences of such incidents (including potential incidents);
  - An estimation of the probability of a major incident;
  - The on-site emergency plan;
  - An estimation of the total result in the case of an explosion;
  - An estimation of the effects of thermal radiation in the case of fire;
  - An estimation of concentration effects in the case of a toxic release;
  - Potential effects of a major incident on an adjacent major hazard installation or part thereof;
  - Potential effects of a major incident on any other installation, members of the public (including all persons outside the premises) and on residential areas;
  - Meteorological tendencies;
  - Suitability of existing emergency procedures for risks identified;
  - Any requirements laid down in terms of the Environmental Conservation Act of 1989 (Act No. 73 of 1989);
  - Any organisational measures that may be required;
- The employer shall ensure that the risk assessment is of an acceptable standard and shall be reviewed should:
  - It be suspected that the preceding assessment is no longer valid;
  - Changes in the process that affect hazardous substances;
  - Changes in the process that involve a substance that resulted in the installation being classified a Major Hazard Installation or in the methods, equipment or procedures for the use, handling or processing of that substance;
  - Incidents that have brought the emergency plan into operation and may affect the existing risk assessment;
- Must be made available at a time and place and in a manner agreed upon between parties for scrutiny by any interested person that may be affected by the activities.

Requirements related to the on-site emergency plan (List 3) are:

- After submission of the notification, the following shall be established:
  - An on-site emergency plan must be made available and must be followed inside the premises of the installation or the part of the installation classified as a Major Hazard Installation, in consultation with the relevant health and safety representative or committee;
  - The on-site emergency plan must be discussed with the relevant local government, taking into consideration any comment on the risk related to the health and safety of the public;
  - The on-site emergency plan must be reviewed and where necessary updated, in consultation with the relevant local government, at least once every three years;
  - A copy of the on-site emergency plan must be signed in the presence of two witnesses, who shall attest the signature;
  - The on-site emergency plan must be readily available at all times for implementation and use;
  - All employees must be conversant with the on-site emergency plan;
  - The on-site emergency plan must be tested in practice at least once a year, and a record must be kept of such testing;
- Any employer, self-employed person and user owning or in control of a pipeline that could pose a threat to the general public shall inform the relevant local government and shall be jointly responsible with the relevant local government for establishment and implementation of an on-site emergency plan.

In reporting of risk and emergency occurrences (List 4):

- Following an emergency occurrence, the user of the installation shall:
  - Subject to the provisions of Regulation 6 of the General Administrative Regulations, within 48 hours by means of telephone, facsimile or similar means of communication, inform the chief inspector, the provincial director and relevant local government of the occurrence of a major incident or an incident that brought the emergency plan into operation or any near miss;
  - Submit a report in writing to the chief inspector, provincial director and local government within seven days;
  - Investigate and record all near misses in a register kept on the premises, which shall at all times be available for inspection by an inspector and local government representatives.

The duties of the supplier refer specifically to:

- Supplying of material safety data sheets for hazardous substances employed or contemplated at the installation;
- Assessment of the circumstances and substance involved in an incident or potential incident and the informing all persons being supplied with that substance of the potential dangers surrounding it;
- Provision of a service that shall be readily available on a 24-hour basis to all employers, self-employed persons, users, relevant local government and any other body concerned to provide information and advice in the case of a major incident with regard to the substance supplied.

The duties of local government are summarised as follows:

" *9. (1) Without derogating from the provisions of the National Building Regulations and Building Standards Act of 1977 (Act No. 103 of 1977), no local government shall permit the erection of a new major hazard installation at a separation distance less than that which poses a risk to:*

(a) Airports;

(b) Neighbouring independent major hazard installations;

(c) Housing and other centres of population; or,

(d) Any other similar facility…

Provided that the local government shall permit new property development only where there is a separation distance which will not pose a risk (our emphasis) in terms of the risk assessment: Provided further that the local government shall prevent any development adjacent to an installation that will result in that installation being declared a major hazard installation.

(2) Where a local government does not have facilities available to control a major incident or to comply with the requirements of this regulation that local government shall make prior arrangements with a neighbouring local government, relevant provincial government or the employer, self-employed person and user for assistance…

(3) All off-site emergency plans to be followed outside the premises of the installation or part of the installation classified as a major hazard installation shall be the responsibility of the local government… "

15 APPENDIX D: PADHI LAND-PLANNING TABLES

15.1 Development Type Table 1: People at Work, Parking

Development Type	Examples	Development Detail and Size	Justification
DT1.1 Workplaces	Offices, factories, warehouses, haulage depots, farm buildings, nonretail markets, builder's yards	Workplaces (predominantly nonretail), providing for less than 100 occupants in each building and less than 3 occupied storeys (Level 1)	Places where the occupants will be fit and healthy and could be organised easily for emergency action Members of the public will not be present or will be present in very small numbers and for a short time
	Exclusions		
		DT1.1 x1 Workplaces (predominantly nonretail) providing for 100 or more occupants in any building or 3 or more occupied storeys in height (Level 2 except where the development is at the major hazard site itself, where it remains Level 1)	Substantial increase in numbers at risk with no direct benefit from exposure to the risk
	Sheltered workshops, Remploy	DT1.1 x2 Workplaces (predominantly nonretail) specifically for people with disabilities (Level 3)	Those at risk may be especially vulnerable to injury from hazardous events or they may not be able to be organised easily for emergency action
DT1.2 Parking Areas	Car parks, truck parks, lockup garages	Parking areas with no other associated facilities (other than toilets; Level 1)	
	Exclusions		
	Car parks with picnic areas or at a retail or leisure development or serving a park and ride interchange	DT1.2 x1 Where parking areas are associated with other facilities and developments the sensitivity level and the decision will be based on the facility or development	

15.2 Development Type Table 2: Developments for Use by the General Public

Development Type	Examples	Development Detail and Size	Justification
DT2.1 Housing	Houses, flats, retirement flats or bungalows, residential caravans, mobile homes	Developments up to and including 30 dwelling units and at a density of no more than 40 per hectare (Level 2)	Development where people live or are temporarily resident It may be difficult to organise people in the event of an emergency
	Exclusions		
	Infill, back-land development	DT2.1 x1 Developments of 1 or 2 dwelling units (Level 1)	Minimal increase in numbers at risk
	Larger housing developments	DT2.1 x2 Larger developments for more than 30 dwelling units (Level 3)	Substantial increase in numbers at risk
		DT2.1 x3 Any developments (for more than 2 dwelling units) at a density of more than 40 dwelling units per hectare (Level 3)	High-density developments
DT2.2 Hotel or Hostel or Holiday Accommodation	Hotels, motels, guest houses, hostels, youth hostels, holiday camps, holiday homes, halls of residence, dormitories, accommodation centres, holiday caravan sites, camping sites	Accommodation up to 100 beds or 33 caravan or tent pitches (Level 2)	Development where people are temporarily resident It may be difficult to organise people in the event of an emergency
	Exclusions		
	Smaller: guest houses, hostels, youth hostels, holiday homes, halls of residence, dormitories, holiday caravan sites, camping sites	DT2.2 x1 Accommodation of less than 10 beds or 3 caravan or tent pitches (Level 1)	Minimal increase in numbers at risk
	Larger: hotels, motels, hostels, youth hostels, holiday camps, holiday homes, halls of residence, dormitories, holiday caravan sites, camping sites	DT2.2 x2 Accommodation of more than 100 beds or 33 caravan or tent pitches (Level 3)	Substantial increase in numbers at risk

Development Type	Examples	Development Detail and Size	Justification
DT2.3 Transport Links	Motorway, dual carriageway	Major transport links in their own right i.e., not as an integral part of other developments (Level 2)	Prime purpose is as a transport link Potentially large numbers exposed to risk but exposure of an individual is only for a short period
	Exclusions		
	Estate roads, access roads	DT2.3 x1 Single carriageway roads (Level 1)	Minimal numbers present and mostly a small period of time exposed to risk Associated with other development
	Any railway or tram track	DT2.3 x2 Railways (Level 1)	Transient population, small period of time exposed to risk Periods of time with no population present

Development Type	Examples	Development Detail and Size	Justification
DT2.4 Indoor Use by Public	Food and drink: restaurants, cafes, drive-through fast food, pubs Retail: shops, petrol filling station (total floor space based on shop area not forecourt), vehicle dealers (total floor space based on showroom or sales building not outside display areas), retail warehouses, super-stores, small shopping centres, markets, financial and professional services to the public Community and adult education: libraries, art galleries, museums, exhibition halls, day surgeries, health centres, religious buildings, community centres. adult education, 6th form college, college of FE Assembly and leisure: Coach or bus or railway stations, ferry terminals, airports, cinemas, concert or bingo or dance halls, conference centres, sports or leisure centres, sports halls, facilities associated with golf courses, flying clubs (e.g., changing rooms, club house), indoor go kart tracks	Developments for use by the general public where total floor space is from 250 m^2 up to 5000 m^2 (Level 2)	Developments where members of the public will be present (but not resident) Emergency action may be difficult to coordinate
	Exclusions		
		DT2.4 x1 Development with less than 250 m^2 total floor space (Level 1)	Minimal increase in numbers at risk
		DT2.4 x2 Development with more than 5000 m^2 total floor space (Level 3)	Substantial increase in numbers at risk
DT2.5 Outdoor Use by Public	Food and drink: food festivals, picnic areas Retail: outdoor markets, car boot sales, funfairs	Principally an outdoor development for use by the general public i.e., developments where	Developments where members of the public will be present (but

Development Type	Examples	Development Detail and Size	Justification
	Community and adult education: open-air theatres and exhibitions Assembly and leisure: coach or bus or railway stations, park and ride interchange, ferry terminals, sports stadia, sports fields or pitches, funfairs, theme parks, viewing stands, marinas, playing fields, children's play areas, BMX or go kart tracks, country parks, nature reserves, picnic sites, marquees	people will predominantly be outdoors and not more than 100 people will gather at the facility at any one time (Level 2)	not resident) either indoors or outdoors Emergency action may be difficult to coordinate
	Exclusions		
	Outdoor markets, car boot sales, funfairs picnic area, park and ride interchange, viewing stands, marquees	DT2.5 x1 Predominantly open-air developments likely to attract the general public in numbers greater than 100 people but up to 1000 at any one time (Level 3)	Substantial increase in numbers at risk and more vulnerable due to being outside
	Theme parks, funfairs, large sports stadia and events, open air markets, outdoor concerts, pop festivals	DT2.5 x2 Predominantly open-air developments likely to attract the general public in numbers greater than 1000 people at any one time (Level 4)	Very substantial increase in numbers at risk, more vulnerable due to being outside Emergency action may be difficult to coordinate

15.3 Development Type Table 3: Developments for Use by Vulnerable People

Development Type	Examples	Development Detail and Size	Justification
DT3.1 Institutional Accommodation and Education	Hospitals, convalescent homes, nursing homes, old people's homes with warden on site or 'on call', sheltered housing, nurseries, crèches, schools and academies for children up to school leaving age	Institutional, educational and special accommodation for vulnerable people or that provides a protective environment (Level 3)	Places providing an element of care or protection Because of age, infirmity or state of health the occupants may be especially vulnerable to injury from hazardous events Emergency action and evacuation may be very difficult
	Exclusions		
	Hospitals, convalescent homes, nursing homes, old people's homes, sheltered housing	DT3.1 x1 24-hour care where the site on the planning application being developed is larger than 0.25 hectare (Level 4)	Substantial increase in numbers of vulnerable people at risk
	Schools, nurseries, crèches	DT3.1 x2 Day care where the site on the planning application being developed is larger than 1.4 hectare (Level 4)	Substantial increase in numbers of vulnerable people at risk
DT3.2 Prisons	Prisons, remand centres	Secure accommodation for those sentenced by court, or awaiting trial, etc. (Level 3)	Places providing detention Emergency action and evacuation may be very difficult

15.4 Development Type Table 4: Very Large and Sensitive Developments

Development Type	Examples	Development Detail and Size	Justification
Note: all Level 4 developments are by exception from Level 2 or 3 and are reproduced in this table for convenient reference			
DT4.1 Institutional Accommodation	Hospitals, convalescent homes, nursing homes, old people's homes, sheltered housing	Large developments of institutional and special accommodation for vulnerable people (or that provide a protective environment) where 24-hour care is provided and where the site on the planning application being developed is larger than 0.25 hectare (Level 4)	Places providing an element of care or protection Because of age or state of health the occupants may be especially vulnerable to injury from hazardous events Emergency action and evacuation may be very difficult The risk to an individual may be small but there is a larger societal concern
	Nurseries, crèches, schools for children up to school leaving age	Large developments of institutional and special accommodation for vulnerable people (or that provide a protective environment) where day care (not 24-hour care) is provided and where the site on the planning application being developed is larger than 1.4 hectare (Level 4)	Places providing an element of care or protection Because of the occupants may be especially vulnerable to injury from hazardous events Emergency action and evacuation may be very difficult The risk to an individual may be small but there is a larger societal concern
DT4.2 Very Large Outdoor Use by Public	Theme parks, large sports stadia and events, open air markets, outdoor concerts, pop festivals	Predominantly open-air developments where there could be more than 1000 people present (Level 4)	People in the open air may be more exposed to toxic fumes and thermal radiation than if they were in buildings Large numbers make emergency action and evacuation difficult The risk to an individual may be small but there is a larger societal concern

16 APPENDIX E: MATERIAL SAFETY DATA SHEETS

16.1 LNG and CNG Modelled as Methane

METHANE	**ICSC: 0291**
Methyl hydride	**February 2000**
CAS #: 74-82-8	
UN #: 1971	
EC Number: 200-812-7	

	ACUTE HAZARDS	PREVENTION	FIRE FIGHTING
FIRE & EXPLOSION	Extremely flammable. Gas/air mixtures are explosive.	NO open flames, NO sparks and NO smoking. Closed system, ventilation, explosion-proof electrical equipment and lighting. Use non-sparking hand tools.	Shut off supply; if not possible and no risk to surroundings, let the fire burn itself out. In other cases, extinguish with water spray, powder, carbon dioxide. In case of fire: keep cylinder cool by spraying with water. Combat fire from a sheltered position.

	SYMPTOMS	PREVENTION	FIRST AID
Inhalation	Suffocation. See Notes.	Use ventilation. Use breathing protection.	Fresh air, rest. Artificial respiration may be needed. Refer for medical attention.
Skin	ON CONTACT WITH LIQUID: FROSTBITE.	Cold-insulating gloves.	ON FROSTBITE: rinse with plenty of water, do NOT remove clothes. Refer for medical attention.
Eyes	ON CONTACT WITH LIQUID: FROSTBITE.	Wear safety goggles.	First rinse with plenty of water for several minutes (remove contact lenses if easily possible), then refer for medical attention.
Ingestion			

SPILLAGE DISPOSAL	CLASSIFICATION & LABELLING
Evacuate danger area! Personal protection: self-contained breathing apparatus. Consult an expert! Ventilation. Remove all ignition sources. NEVER direct water jet on liquid.	**According to UN GHS Criteria**
STORAGE	
Fireproof. Cool. Ventilation along the floor and ceiling.	**Transportation** **UN Classification** UN Hazard Class: 2.1
PACKAGING	

International Labour Organization | World Health Organization | Prepared by an international group of experts on behalf of ILO and WHO, with the financial assistance of the European Commission. | European Commission

METHANE	**ICSC: 0291**

PHYSICAL & CHEMICAL INFORMATION

Physical State; Appearance COLOURLESS ODOURLESS COMPRESSED OR LIQUEFIED GAS. **Physical dangers** The gas is lighter than air. **Chemical dangers**	Formula: CH_4 Molecular mass: 16.0 Boiling point: -161°C Melting point: -183°C Solubility in water, ml/100ml at 20°C: 3.3 Relative vapour density (air = 1): 0.6 Flash point: Flammable gas Auto-ignition temperature: 537°C Explosive limits, vol% in air: 5-15 Octanol/water partition coefficient as log Pow: 1.09

EXPOSURE & HEALTH EFFECTS

Routes of exposure The substance can be absorbed into the body by inhalation. **Effects of short-term exposure** Rapid evaporation of the liquid may cause frostbite.	**Inhalation risk** On loss of containment this substance can cause suffocation by lowering the oxygen content of the air in confined areas. **Effects of long-term or repeated exposure**

OCCUPATIONAL EXPOSURE LIMITS

ENVIRONMENT

NOTES

Density of the liquid at boiling point: 0.42 kg/l.
High concentrations in the air cause a deficiency of oxygen with the risk of unconsciousness or death.
Check oxygen content before entering area.
Turn leaking cylinder with the leak up to prevent escape of gas in liquid state.
After use for welding, turn valve off; regularly check tubing, etc., and test for leaks with soap and water.
The measures mentioned in section PREVENTION are applicable to production, filling of cylinders, and storage of the gas.
Other UN number: 1972 (refrigerated liquid), Hazard class: 2.1.