APPENDIX 25
ARROW LNG PLANT
Preliminary Safety Management Study

arrow energy
go further

PRELIMINARY SAFETY MANAGEMENT STUDY IN ACCORDANCE WITH AS2885.1 OF ARROW ENERGY'S LNG PROJECT: FEED GAS PIPELINE, GLADSTONE, QUEENSLAND

Prepared for: Arrow CSG Australia Pty Ltd and Coffey Environments Australia Pty Ltd

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Prepared by: Karin Nilsson

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Planager Pty Ltd
PO Box 1497
Lane Cove NSW 2066
Telephone: [02] 9427 7851
Facsimile: [02] 9427 7851
www.planager.com.au

Preliminary Safety Management Study in Accordance With AS2885.1 of Arrow Energy's LNG Project: Feed Gas Pipeline, Gladstone, Queensland

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ATTACHMENTS

EXECUTIVE SUMMARY

Arrow CSG (Australia) Pty Ltd (Arrow Energy) proposes to develop a feed gas pipeline to support a liquefied natural gas (LNG) plant on Curtis Island off the central Queensland coast near Gladstone.

An Environmental Impact Statement (EIS) is being prepared to assess potential impacts of the project and ensure that appropriate measures are in place to manage the identified impacts. This risk assessment responds to the terms of reference (TOR), (Ref [1]) for the EIS and assesses the hazards and risks to people, the environment and property associated with the feed gas pipeline, which forms part of the Arrow LNG Plant.

The risk assessment process, as detailed in AS2885.1-2007, *Pipelines – Gas and Liquid Petroleum – Design and Construction* (Ref 2), is referred to as a *Safety Management Study* (SMS). The present risk assessment has used the same terminology.

This initial SMS has been undertaken to:

- Formally identify the potential threats to the health and safety of people in the area, the natural environment and the integrity of the feed gas pipeline.
- Review the preventative and protective measures of the feed gas pipeline and associated tunnel, and their effectiveness in controlling the potential hazardous incidents associated with the pipeline.
- Determine the risk associated with the feed gas pipeline at this location.
- Determine risk reduction, using the ALARP (As Low As Reasonably Practical) approach.

The risks associated with the feed gas pipeline are assessed across its complete life cycle, as follows:

- Construction and commissioning, including digging, trenching and under boring of pipelines using thrust boring and tunnel boring machine), constructing plant and equipment, and commissioning (i.e., bringing the equipment into production);
- Operation and maintenance; and
- Decommissioning and rehabilitation.

The types of risks considered in the SMS are:

- Acute risk of human injury or fatality;
- Acute risk of propagation of an incident to neighbouring facilities or damage to property;
- Serious damage to the natural environment following a major incident at the pipeline.

The risk associated with the loss of supply of gas to the LNG plant is not included in this initial SMS as the safe shut down of the plant would occur without leading to a threat to the health and safety of people or to the integrity of the pipeline or to the natural environment.

The present SMS has considered a wide range of threats that may affect the feed gas pipeline, health and safety of people adjacent to the pipeline and the natural environment in the vicinity of the pipeline.

All threats identified for the pipeline were evaluated in terms of consequences and likelihood and the risk as evaluated in accordance with the risk matrix set out in AS2885.1.

With mitigating controls in place, the residual risks were ranked at either *Low* or *Intermediate* (with a 50:50 split). No residual risks were ranked High, and hence there were no critical risk management actions.

Seven threats were classified as Intermediate.

- The controls in place or proposed for six of the seven *Intermediate* risks were found to adhere to ALARP principles.
- The controls for one of the seven *Intermediate* risks are still in their preliminary design. These included:
  - The risk to personnel during access to the tunnel due to exposure of asphyxiant or flammable gases; and
  - The confinement of flammable gases with subsequent ignition and explosion inside the tunnel.

The assessment of risk against ALARP principles for the tunnel design will continue as the design progresses. The risk management measures, being explored at this stage in the project, were reviewed in the present SMS, leading to the assessment of risk associated with the conceptual design of the tunnel as ALARP, provided the design of the risk control measures progresses through the design stages. The SMS process will therefore be continued through further design and formalised within the detailed SMS process.

The future detailed SMS shall determine exact physical and procedural measures, assess whether these measures eliminate the threat, assign consequence and likelihood values to non-eliminated threats, determine the risk ranking, assign appropriate risk treatment actions and monitor the ongoing effectiveness of these actions.

GLOSSARY AND ABBREVIATIONS

ALARP	As Low as Reasonably Practicable. The term refers to the principle of reducing residual risk to a level where the cost of reducing the risk further would be disproportionate to the benefit gained.
ANSI	American National Standards Institute
API	American Petroleum Institute
Arrow Energy	Arrow CSG (Australia) Pty Ltd
CIC	Common Infrastructure Corridor
EGIG	European Gas Pipeline Incident Data Group
EIS	Environmental Impact Statement
ERP	Emergency Response Plan
FEED	Front End Engineering Design
GGS	Gas Gathering Station
GIL	Gas Insulated Lines
HAZID	Hazard Identification
HSE	Health, Safety and Environment
JSEA	Job Safety and Environment Analysis. Usually part of a PTW system, allows a structured review of work to be carried out, to ensure safety and environmental issues are properly addressed.
LNG	Liquefied Natural Gas
MAOP	Maximum Allowable Operating Pressure
MHF	Major Hazard Facilities
MPa(g)	Mega Pascal gauge (pressure unit)
MSDS	Material Safety Data Sheet
MW	Mega Watt (power unit)
NDT	Non-Destructive Testing. Methods used to test the integrity of piping and pressure vessels
OFC	Optical Fibre Cable

PPE	Personal Protective Equipment
PTW	Permit to Work. System for managing and controlling work activities in complex and hazardous work environments designed to ensure appropriate authorities and controls are in place prior to and during work activities.
SCADA	Supervisory Control and Data Acquisition. An industrial telemetry system that coordinates the acquisition and communication of data, often in geographically disparate locations.
SMS	Safety Management Study
TOR	Terms of Reference
VHF	Very High Frequency. Used to describe radio communications

REPORT

1 INTRODUCTION

1.1 BACKGROUND

Arrow CSG (Australia) Pty Ltd (Arrow Energy) proposes to develop a liquefied natural gas (LNG) facility on Curtis Island off the central Queensland coast near Gladstone. The project, known as the Arrow LNG Plant, is a component of the larger Arrow LNG Project.

The proponent is a subsidiary of Arrow Energy Holdings Pty Ltd which is wholly owned by a joint venture between subsidiaries of Royal Dutch Shell plc and PetroChina Company Limited.

Arrow Energy proposes to construct the LNG plant in the Curtis Island Industry Precinct at the southwestern end of Curtis Island, approximately 6 km north of Gladstone and 85 km southeast of Rockhampton, off Queensland’s central coast. In 2008, approximately 10% of the southern part of the island was added to the Gladstone State Development Area to be administered by the Queensland Department of Local Government and Planning. Of that area, approximately 1,500 ha (25%) has been designated as the Curtis Island Industry Precinct and is set aside for LNG development. The balance of the Gladstone State Development Area on Curtis Island has been allocated to the Curtis Island Environmental Management Precinct, a flora and fauna conservation area.

The Arrow LNG plant will be supplied with coal seam gas from gas fields in the Surat and Bowen basins via high-pressure gas pipelines to Gladstone, from which a feed gas pipeline will provide gas to the LNG plant on Curtis Island. A tunnel is proposed for the feed gas pipeline crossing of Port Curtis.

An approximately 9km long feed gas pipeline will supply gas to the LNG plant from its connection to the Arrow Surat Pipeline (formerly the Surat Gladstone Pipeline) on the mainland adjacent to Rio Tinto’s Yarwun alumina refinery.

1.2 SCOPE AND AIM

An Environmental Impact Statement (EIS) is being prepared to assess potential impacts of the project and ensure that appropriate measures are in place to manage the identified impacts.

This risk assessment responds to the terms of reference (TOR), (Ref [3]) for the EIS and assesses the threats to the pipeline and consequences, to the public and the environment, of failure of the feed gas pipeline, which forms part of Arrow LNG Plant. The TOR state:

> *A risk assessment in accordance with Australia/New Zealand Standard AS/NZS 2885 Gas and Liquid Petroleum Pipelines should be conducted on the gas transmission pipeline from Gladstone City Gate to the LNG plant on Curtis Island. The results of the location analysis and threat analysis and calculation of ‘measurement lengths’ should be presented together with management strategies which will be employed to deliver the safety principles of the standard that require risks to be reduced to as low as reasonably practical, low or negligible.*

The risk assessment process, is detailed in Part 1 of the standard (AS2885.1-2007, *Pipelines – Gas and Liquid Petroleum – Design and Construction* (Ref 4)) and is referred to as a *Safety Management Study* (SMS). The risk assessment presented in this report has used the same terminology.

This initial SMS has been undertaken to:

- Formally identify the potential threats to the health and safety of people in the area, the natural environment and the integrity of the feed gas pipeline.
- Review the preventative and protective measures of the feed gas pipeline and associated tunnel, and their effectiveness in controlling the potential hazardous incidents associated with the pipeline.
- Determine the risk associated with the feed gas pipeline at this location.
- Determine risk reduction, using the ALARP (as low as reasonably practicable) approach.

The risks associated with the feed gas pipeline are assessed across its complete life cycle, as follows:

- Construction and commissioning, including digging, trenching and under boring of pipelines (using thrust boring and tunnel boring machine), construction plant and equipment, and commissioning (i.e., bringing the pipeline into operation);
- Operation and maintenance; and
- Decommissioning and rehabilitation.

The types of risks considered in the SMS are:

- Acute risk of human injury or fatality;
- Acute risk of propagation of an incident to neighbouring facilities or damage to property;
- Serious damage to the natural environment following a major incident at the pipeline.

The risk associated with the loss of supply of gas to the LNG plant is not included in this initial SMS as the safe shut down of the plant would occur without leading to a threat to the health and safety of people or to the integrity of the pipeline or to the natural environment (if this safe shutdown resulted in a venting or flaring of the plant there would be environmental implications, as discussed in the EIS).

The LNG plant, supporting infrastructure, and the LNG jetty are considered as part of a separate hazard and risk assessment (Ref 5).

2 FACILITIES INCLUDED IN THE INITIAL SAFETY MANAGEMENT STUDY

This initial SMS considers the feed gas pipeline within the scope of the EIS, from the mainland in Gladstone through to the pig receiver at the arrival point at the LNG plant on Curtis Island. The components of the feed gas pipeline, the tunnel and pipeline operation covered by this SMS are described below.

2.1 OVERVIEW

The feed gas pipeline will be constructed in three sections:

- A short length of feed gas pipeline will run from the proposed Arrow Surat Pipeline to the tunnel launch shaft, which will be located on a mudflat south of Fishermans Landing, just south of Boat Creek. This section of pipeline will be constructed using conventional open-cut trenching methods within a 40-m wide construction right of way.
- The next section of the feed gas pipeline will traverse Port Curtis harbour in a tunnel to be bored under the harbour from the mainland tunnel launch shaft to a receival shaft on Hamilton Point. The tunnel under Port Curtis will have an excavated diameter of up to approximately 6 m and will be constructed by a tunnel boring machine that will begin work at the mainland launch shaft. Tunnel spoil material will be processed through a de-sanding plant to remove the bentonite and water and will comprise mainly a finely graded fill material, which will be deposited in an engineered spoil placement area constructed adjacent to the launch shaft. Based on the excavated diameter, approximately 223,000 m^3 of spoil will be treated as required for acid sulfate soil and disposed of at this location.
- From the tunnel receival shaft on Hamilton Point, the remaining section of the feed gas pipeline will run underground to the LNG plant, parallel to the above ground cryogenic pipelines. This section will be constructed using conventional open-cut trenching methods within a 30-m wide construction right of way. A permanent easement up to 30-m wide will be negotiated with the relevant land manager or owner.

Should one of the electrical plant power options be chosen, it is intended that a power connection will be provided by a third party to the tunnel launch shaft, whereby Arrow Energy would construct a power cable within the tunnel to the LNG plant.

Other infrastructure, such as communication cables, water and wastewater pipelines, may also be accommodated within the tunnel.

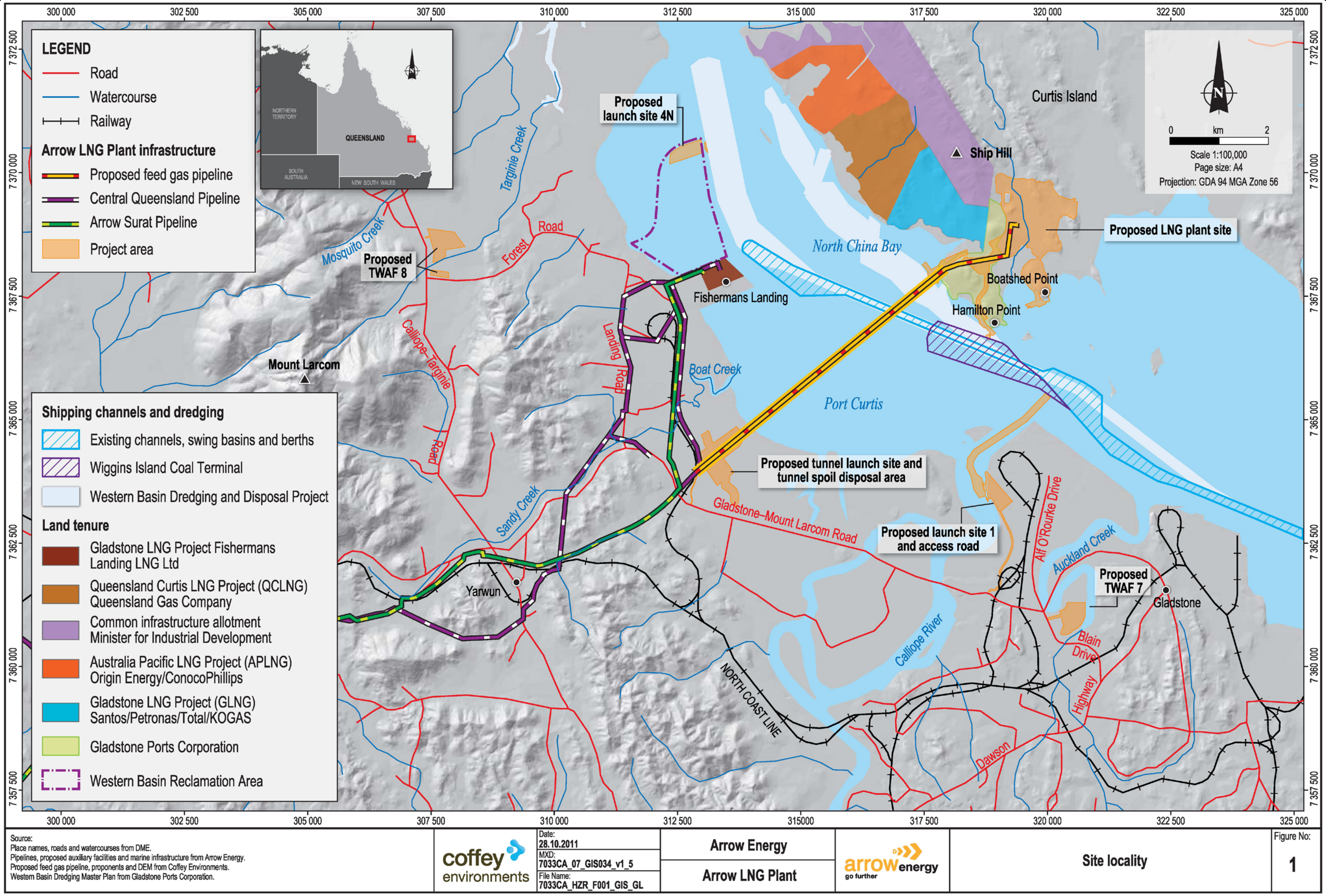

Figure 1 – Site Locality Including Feed Gas Pipeline Alignment

2.2 FEED GAS PIPELINE

The feed gas pipeline will include the following elements:

- An approximately 9 km long pipeline with an external diameter of 1,219 mm (48") - possibly up to 1,422 mm (56");
- A pig receiving facility at the LNG plant.

AS2885.1 provides guidance on the required wall thickness of pipelines depending on maximum allowable operating pressure. The wall thickness will not be less than that required for pressure containment (hoop stress) determined from the design pressure and a design factor. The wall thickness calculations will also consider external loads from road and railway crossings as well as those imposed as a result of construction / installation, testing, commissioning and operating and incidental loads. Consideration will also be given to the effect of temperature differential during installation, operation and maintenance. The equivalent stress thus calculated will be within the limits specified in AS 2885.1 Section 5.

The pipeline is expected to operate at a pressure of between 8.1 MPa(g) (at the inlet of the pipeline) and 7.3 MPa(g) at the LNG plant battery limit. The pipeline will be designed for a Maximum Allowable Operating Pressure (MAOP) of up to 15.3 MPa(g). Depressurisation of the feed gas pipeline, as required for emergency response purposes and for limited major maintenance activities, will be done using the available facilities for plant flaring at the Curtis Island LNG plant.

2.3 TUNNEL

The feed gas pipeline will run within a tunnel under the harbour across to Curtis Island.

The tunnel will be up to 6.5 km long and 4.6 m (internal) diameter (up to 6 m external diameter) to contain the gas pipeline and any other utilities. The tunnel will be excavated at approximately 35 m below sea level to ensure that the entire alignment runs through competent rock.

The tunnel is planned to be kept ventilated, with lighting provided for access to the different utilities during construction and operation.

The following utilities and features may be housed within the tunnel:

- Feed gas pipeline
- Power cables
- Water supply pipeline
- Sewer line/s
- Telecommunication lines
- Ventilation ducts
- Limited personnel access within the tunnel

2.4 POWER SUPPLY

The base concept for power generation at the LNG plant is to use gas turbines (referred to as "All Mechanical"). One option being considered is to import all power and install electric motors at the plant instead of gas turbines. In this option, the tunnel would be used as a conduit to deliver the power via 275 kV power cables or gas insulated lines (GIL) from the mainland to Curtis Island. Electrical power of up to 450 MW for two trains (and 900 MW for four trains) may be imported from the local grid via the tunnel.

2.5 OPERATING CONDITIONS

Gas from the Bowen and Surat basins will arrive at a landing pressure of 7.3 MPa(g) upstream of the LNG plant.

The feed gas pipeline and its components (metering, valves and fittings) will be designed for an ANSI 900 class to meet the requirements of a 15.3 MPa(g) MAOP or for an ANSI 600 class if the MAOP is 10.2 MPa(g).

2.6 PROPERTIES

The composition of the feed gas is predominantly methane gas (about 95 to 98%), with some nitrogen and carbon dioxide. The gas may include very small quantities of ethane, propane and butane (less than 0.05%).

The gas is a buoyant, flammable gas, which is lighter than air (relative density of 0.6). On release in the open the non-ignited gas tends to disperse rapidly at altitude. On release in an enclosed area an explosion or a flash fire is possible. Ignition at the point of release is possible for the pressurised gas, in which case the gas would burn as a jet (or torch) flame.

The physical properties of methane gas (as representative of the feed gas) are listed in the table below:

Table 1 – Properties of Methane Gas

Molecular Weight (g/mol)	17
Relative density of the gas (atmospheric temp. and pressure)	0.6
Heat of combustion (MJ/kg)	50
Flammable range (vol. % in air)	5 to 15
Ratio of specific heats (Cp + Cv)	1.31
Flash point	188^{o}C

2.7 CONTROL AND COMMUNICATION SYSTEMS

Continuous monitoring and operation of the feed gas pipeline will be managed remotely from the control room. The pipeline system will be equipped with a supervisory control and data acquisition (SCADA) system that will monitor and control the conditions on the pipeline and GGS. The SCADA system will have the capability to monitor line pressures, gas flow rates and other variables and detect abnormal conditions caused by leaks, overpressure or damage by third parties. The system also has the capability to open/close isolation valves remotely.

The SCADA is the system employed by all major pipelines. Operational variables on the GGS and the feed gas pipeline will be sent to the control room. Abnormal conditions will be alerted by means of alarms, which will notify the pipeline operators if an abnormal condition exists. In the event of alarms, a shutdown can be triggered. The SCADA also has a backup.

The feed gas pipeline will require regular inspections and patrols.

2.8 SUMMARY OF DESIGN PARAMETERS AND ASSUMPTIONS USED FOR THE STUDY

The design of the feed gas pipeline is in the early conceptual phase and not all details were known for the preparation of this initial SMS. In such cases, a number of assumptions have to be made and are listed in Table 2 below. The assumptions are conservative in nature to allow for detailed design variations. As detailed design proceeds, any deviations from these assumptions will be incorporated into future SMSs.

Table 2 – Equipment and Facilities Configuration – Assumptions Made for the Initial SMS

Component	Function	Material of construction	Wall thickness [mm]	Diameter (external) [mm]	Length	Operating Conditions
Feed gas pipeline	Transport of gas to the LNG plant	ANSI 900 class	Design will follow AS2885.1 requirements. Wall thickness of 18 mm to 21 mm will suffice to prevent against a rupture, depending on the final pipeline diameter.	1,219 mm to maximum 1,422 mm	9 km	- MAOP: up to up to 15.3 MPa(a) - Operating pressure: 7.3 to 8.1 MPa(g) - Temperature: summer: max 27^{o}C; winter: min 7^{o}C

3 STUDY METHOD

3.1 METHODOLOGY

The initial SMS for the feed gas pipeline was carried out in accordance with AS2885.1 (Ref 22), paragraph B3.1.1. Figure 2 below illustrates the pipeline safety management study process. Each of the following steps is further detailed below.

a) Location and zoning information/location class/environmental sensitivity assessments/leading to definition of high consequence areas.

b) Threat identification (both typical and location-specific threats).

c) Basic pipeline design parameters, including application of physical, procedural and design measures to identified threats and review and control of failure threats.

d) Assessment of residual risk from failure threats.

e) The energy release rate and the contour radius for a radiation intensity of 4.7 and 12.6 kW/m^2 in the event of a full bore rupture.

f) Demonstrate ALARP.

3.1.1 Location Class Analysis

The location class analysis classifies an area according to its general geographic and demographic characteristics, possible threats to pipeline integrity, risks to people, property and the environment and sensitivity of the surrounding land usage.

The pipeline alignment is divided into class locations where the land use and sensitivity are consistent. The location analysis is undertaken through a detailed review of the pipeline alignment using layout diagrams, maps and aerial photography.

The location class is selected from an analysis of the predominant land use in the broad area traversed by the pipeline and is framed by the *measurement length*, i.e. the distance from the centreline of the pipeline to radiation contour for a full bore rupture that may cause injury.

Each section is allocated a *primary* location class and, where applicable, a *secondary* location class, in accordance with AS2885.1.

A brief description of the primary location classes given in AS2885.1 is provided below:

- Rural (R1) – Land that is unused, undeveloped or is used for rural activities.
- Rural Residential (R2) – Land that is occupied by single residence blocks typically in range 1 ha to 5 ha.
- Residential (T1) – Land that is developed for community living (i.e. where multiple dwellings exist in proximity to each other and are served by common public utilities).
- High Density (T2) – Land that is developed for high density community use (i.e. where multistorey development predominates or where large numbers of people congregate in the normal use of the area).

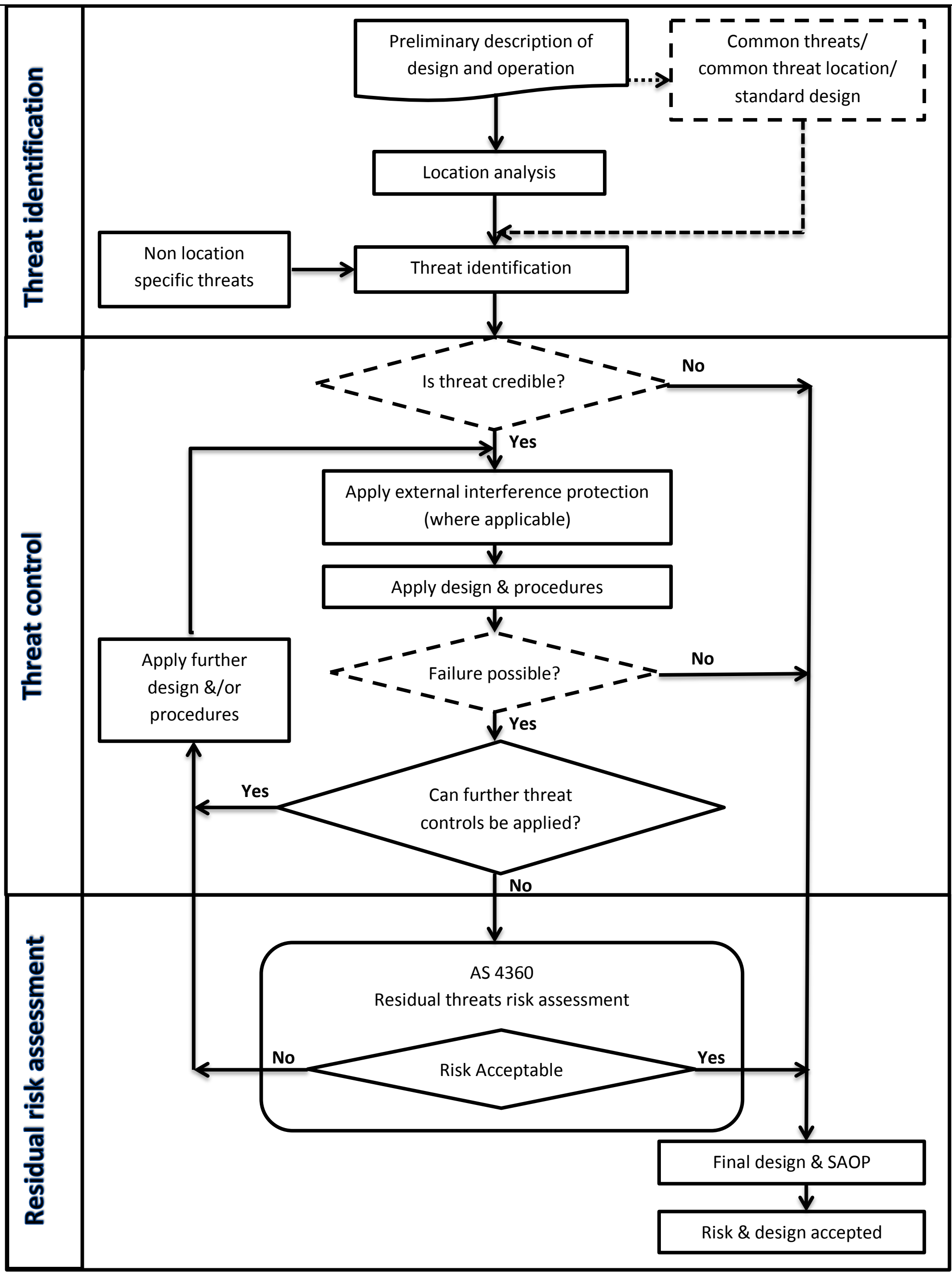

Figure 2 – Pipeline Safety Management Process

Brief descriptions of the secondary location classes are:

- Sensitive Use (S) – Areas where consequence of failure may be increased, (i.e. schools, hospital and aged care facilities). T2-design requirements apply in sensitive use areas.
- Industrial (I) – Industrial locations are land that poses a different range of threats because of its development. T1-design requirements apply in industrial areas.
- Heavy Industrial (HI) – Site development or zoned for use of heavy industry or for toxic industrial use.
- Submerged (W) – Land that is continuously or occasionally inundated with water, (i.e. lakes, harbours, flood plains, watercourses and creeks), whether permanent or seasonal.
- Common Infrastructure Corridor (CIC) – Multiple infrastructure developments within a common easement or reserve.

3.1.2 Threat Identification

The threat identification stage considers all threats with the potential to damage the feed gas pipeline, cause release of gas from the pipeline, or cause harm to the pipeline operators, the public or the environment.

Threats to the safety and integrity of the feed gas pipeline were identified and assessed. For each threat, the location is specified and the consequences and effects of the threat occurring are identified. Both typical (generic) threats and location-specific threats were considered.

3.1.3 Identification of Safeguards and Controls

The proposed safeguards and controls for each credible threat were reviewed.

Types of safeguards and controls can relate to prevention of the threat, protection of personnel, equipment and environment or the development and implementation of emergency procedures. Examples include external interference protection, design safeguards and procedures both for the construction phase and for the operation and maintenance phase.

3.1.4 Review of Failure Threats

A failure analysis was conducted for threat scenarios where the identified controls may not prevent failure. The aim of the failure analysis was to determine the likely damage to the pipeline, its mode of failure and where applicable, the energy release rate at that point.

Causes of failure considered for this pipeline included rupture, hole, pinhole, crack, dent, and gouge, and loss of wall thickness.

3.1.5 Assessment of Residual Risk

The residual risk associated with each threat after control measures have been applied can then be assessed, taking into account both the failure analysis and an estimated likelihood of failure. The methodology set out in AS2885.1 was followed using the risk matrix presented in Table 3 below. Under this approach, each threat is assigned both a consequence ranking and frequency or likelihood ranking.

The consequence relates to the potential impacts on different receptors (people, supply and/or the environment) ranging from catastrophic (e.g. multiple fatalities) through to negligible (e.g. minimal impact on health). In this study, the consequence of loss to supply of gas to the LNG plant has not been considered as it would cause shut down of the plant without leading to a threat to the health and safety of people or to the integrity of the pipeline. Threats to the environment, relating to shut down of the LNG plant and flaring of inventories, are discussed in the Air Quality Technical Study, included in the EIS.

The likelihood of a threat occurring relates to whether it may occur frequently (i.e. expected to occur several times in the life of the project) through to hypothetical where the threat is theoretically possible but has ever occurred on a similar pipeline.

The risk matrix from AS2885.1 then assigns a risk ranking as a function of both the consequence and likelihood. Risk rankings range from extreme risk through to high, intermediate, low and negligible.

Table 3 – AS2885.1 Risk Matrix

CONSEQUENCE RANKING TABLE			C O N S E Q U E N C E S				
			CATASTROPHIC	**MAJOR**	**SEVERE**	**MINOR**	**NEGLIGIBLE**
R E C E P T O R S	PEOPLE:		Multiple fatalities	Few fatalities, or several people with lifethreatening injuries	Injury or illness requiring hospital treatment	Injuries requiring first aid treatment	Minimal impact on health
	SUPPLY:		Long term interruption	Prolonged interruption or long-term restriction	Short term interruption or prolonged restriction	Short term interruption or restriction but shortfall met from other sources	No interruption or restriction
	ENVIRONMENT:		Effects widespread, viability of ecosystems or species affected, permanent major changes	Major off-site impact or long-term severe effects or rectification difficult	Localised (<1 ha) & shortterm (<2 yr) effects, easily rectified	Effect very localised (<0.1 ha) and very short term (weeks), minimal rectification	No effect, or minor on-site effects rectified immediately with negligible residual effect
RISK MATRIX			CONSEQUENCES				
F R E Q U E N C Y	Frequent	Expected to occur several times (! 10 events)	**EXTREME**	**EXTREME**	**HIGH**	**INTERMEDIATE**	**LOW**
	Occasional	May occur occasionally (0.1 - 10 events)	**EXTREME**	**HIGH**	**INTERMEDIATE**	**LOW**	**LOW**
	Unlikely	Unlikely to occur but possible (0.1% - 10% probability)	**HIGH**	**HIGH**	**INTERMEDIATE**	**LOW**	**NEGLIGIBLE**
	Remote	Not anticipated for this pipeline at this location (0.001 - 0.1% probability)	**HIGH**	**INTERMEDIATE**	**LOW**	**NEGLIGIBLE**	**NEGLIGIBLE**
	Hypothetical	Theoretically possible but has never occurred on a similar pipeline (<0.001% probability)	**INTERMEDIATE**	**LOW**	**NEGLIGIBLE**	**NEGLIGIBLE**	**NEGLIGIBLE**

3.1.6 Demonstrate ALARP

The requirement in AS2885.1 is that risk rankings determined to be *Negligible* or *Low* or demonstrated to be ALARP are accepted risks.

In accordance with AS2885.1, a risk cannot be demonstrated as ALARP until consideration has been given to means of further reducing the risk and the reasons why these further means have not been adopted. ALARP is achieved when the cost of further risk reduction measures is grossly disproportionate to the benefit gained from the reduced risk that would result.

3.2 STUDY INPUTS

Input to the initial SMS included a conceptual hazard identification study of the feed gas pipeline and the power transmission media through the tunnel (Ref 6).

The conceptual hazard identification study included a brainstorm of the pipeline and tunnel design, construction and operation against a list of topics to identify potential threats to people safety, pipeline integrity and damage to the environment. In regard to the tunnel these topics included the potential for water ingress; access issues; co-location of gas and electricity in tunnels; potential impact and third party damage, seismic effect, activities for manual handling, maintenance, construction, sequencing and scheduling, potential for fires, explosions and loss of containment, potential for the creation of magnetic field, hazardous interaction with other systems, potentially poor air quality and accumulation of toxics, and emergency response. Other topics included ensuring reliability, communications systems, and security systems. Threats to the pipeline included those threats listed in Appendix C of AS2885.1.

Other inputs to the SMS included an assessment of hazardous properties of the gas (see Appendix 1) and a review of historical incidents involving cross country pipelines. Layout diagrams of the pipeline route were also reviewed as well as design features, the surrounding land usage, and the safety management systems which will be in place to manage the operation of pipeline.

4 SAFETY MANAGEMENT STUDY

4.1 LOCATION ANALYSIS

The location analysis has considered the feed gas pipeline in three sections as follows:

- Section 1: From the Arrow Surat Pipeline to the tunnel launch shaft.
- Section 2: Within the tunnel between the launch shaft on the mainland and the receival shaft on Hamilton Point.
- Section 3: From the receival shaft on Hamilton Point to the LNG plant.

The proposed primary and secondary location class for each section of the feed gas pipeline is presented in Table 4 below.

Table 4 - Location Classes

Section	Land Usage	Proposed Classification
Section 1 – From the Arrow Surat Pipeline to the Tunnel Launch Shaft	Within Gladstone State Development Area Infrastructure Corridor.	Primary: High Density (T2)- large numbers of people may congregate within a measurement length, in the normal use of the area Secondary: Heavy Industrial (HI)
Section 2 – Within the Tunnel between the Launch Shaft on the Mainland to the Receival Shaft on Hamilton Point	Submerged crossing within tunnel traversing Port Curtis harbour.	Primary: High Density (T2) - large numbers of people may congregate within a measurement length, in the normal use of the area Secondary: Submerged (W)
Section 3 – From the Receival Shaft on Hamilton Point to the LNG Plant	Underground to the LNG plant, parallel to the above ground cryogenic pipelines.	Primary: High Density (T2)- large numbers of people may congregate within a measurement length, in the normal use of the area Secondary: Heavy Industrial (HI)

4.2 THREAT IDENTIFICATION AND APPLICATION OF SAFEGUARDS AND CONTROLS

The threats that may cause damage or failure of the feed gas pipeline were identified and assessed for each of the three stages of the project: construction and commissioning; operation; and decommissioning.

The potential hazardous consequences and associated proposed and recommended mitigating strategy (safeguards and controls) for these potential threats are presented in the tables in Appendix 1.

Sixteen threats were identified across the three stages as follows:

Construction and Commissioning

1. Release of flammable or combustible material (e.g. fuel used for construction, hydraulic oil for rotating machinery) due to damage to storage vessels, hoses or pipes.

2. Injury to construction worker due to crushing, being struck by falling equipment or dropped object, slip, trip and falls, being struck by moving equipment, manual handling hazards, working at heights, excessive heat or cold from objects, pressure burst, working in isolation.
3. Electrocution from electrical power line impacts, third party equipment impacts, non-intrinsically safe equipment, lightning, battery fire and explosion or battery storage incident.
4. Loss of containment from storage or during handling of hazardous and environmentally pollutant materials, e.g., during unloading or transfer.
5. Confined space hazards (e.g. from flooding of the tunnel or to exposure fumes / asphyxiation) to operators and contractors.
6. Use of heavy machinery and vehicles or access track.
7. Ignition of flammable gas during blow-out of construction material from pipeline. This threat was determined to be Non Credible due to safeguards in place but listed here for reference.

Operation

8. Generic threats to the pipeline, including:
   - Corrosion.
   - Fault in design, materials, manufacturing, installation, maintenance.
   - Mechanical damage of pipeline or pipeline coating.
   - Terrorism, sabotage, security event.
9. Loss of containment of gas into tunnel, confining the flammable gas cloud. If the cloud ignites, there is the potential for explosion.
10. Loss of containment of flammable gas to atmosphere due to natural causes such as:
    - Earthquake
    - Land subsidence
    - Cyclones, major storms threaten the tunnel entrance and hence the feed gas pipeline.
11. Flooding of tunnel.
12. Threat to people whilst accessing the tunnel during inspection and maintenance routines due to:
    - Electrocution
    - Confined space / congestion
    - Exposure to fumes or asphyxiation due to inadequate ventilation
    - Slips, trips and falls
13. Failure to properly purge the pipeline with inert gas prior to operational start-up, resulting in ignition of flammable gas and air present inside pipeline.

Decommissioning

14. Failure to properly purge the pipeline with inert gas prior to shut down and isolation, resulting in ignition of flammable gas and air present inside pipeline.

15. Injury to decommissioning worker due to failure of manual handling procedure or equipment.
16. Injury due to electrocution.

4.3 REVIEW AND CONTROL OF FAILURE THREATS

4.3.1 Penetration Resistance

The pipeline will be designed through its full length for *no rupture*, such that rupture of the pipeline will not be credible failure mode. This is following AS2885.1 requirements for a pipeline in this location.

The pipe diameter, MAOP of the pipeline, the pipe grade (material) and the pipeline wall thickness are combined to calculate the critical defect lengths, using the methodology provided in AS2885.1 Section 4.11 and Appendix M. The acceptability of the pipeline penetration resistance will be further considered during FEED in reaching a final decision regarding MAOP and wall thickness.

The pipeline will be designed such that the maximum possible penetrated hole size is less than the critical defect length, ensuring that a full bore rupture resulting from third party interference is not credible.

Other failures (from causes other than third-party interference) are possible, for example corrosion that progresses to the rupture scenario, but this will also result in a defect shorter than the critical defect length.

4.3.2 Energy Release and Radiation

Calculation of heat radiation distances and gas release rates were performed in based on the American Petroleum Institute (API) guideline API 521 (Ref 7) and presented in Table 5 below. These calculations will be refined during detailed design process.

For the calculations, approximate values for methane gas are as follows: Specific gravity: 0.6, molecular weight: 17, ratio of specific heat: 1.31, the fraction of heat radiated: 0.25, relative humidity: 30% and assumed temperature: 20^{o}C.

As shown in the table below, the *measurement length* proposed for the pipeline is about 1.5km radius from the 1,220mm diameter pipeline and 1.8km radius from the 1,422mm diameter pipeline (to be refined I the detailed design process).

Table 5 – Mass Flow Rate and Heat Radiation Distances

Hole Diameter (mm)	**10**	**50**	**75**	**90**	**1184 (full bore)**
Option 1 – External diameter pipeline: 1,220mm					
Mass Flow Rate (kg/s)	1.5	37.0	83.2	119.8	14064
Heat Release (Gigawatts)	0.1	1.4	3.2	4.6	537
Distance to radiation Contour: 12.6kW/m^2 (m)	9	47	71	85	921
Distance to radiation Contour: 4.7kW/m^2 (m)	15	77	116	139	1507
Hole Diameter (mm)	**10**	**50**	**75**	**90**	**1380 (full bore)**
Option 2 – External diameter pipeline: 1,422mm					
Mass Flow Rate (kg/s)	1.5	37.0	83.2	119.8	19106

Heat Release (Gigawatts)	0.1	1.4	3.2	4.6	729
Distance to radiation Contour: 12.6kW/m^2 (m)	9	47	71	85	1073
Distance to radiation Contour: 4.7kW/m^2 (m)	15	77	116	139	1757

4.4 Assessment of Residual Risk

A risk assessment was completed for each of the threats identified for the feed gas pipeline on the basis that all of the controls listed in the column entitled *Typical Controls* in Appendix 1 are implemented and are effective.

The risk of the threats identified for the project (following implementation of control measures) was assessed and each threat assigned a risk ranking.

The following tables present the residual risk profiles for the three phases of the project.

All threats where the risk is identified as Intermediate require justification against ALARP principles, as per AS2885.1 requirements.

Table 6 – Risk Profile, Construction Phase

Threat Analysis (initiating causes)	Conse-quences	Likeli-hood	Risk	ALARP Justification Required
1. Fire involving flammable or combustible material used for construction due to damage to storage vessels, hoses or pipes, resulting in threat to people, pipeline integrity or the natural environment.	Major	Hypo-thetical	Low	NO
2. Construction-related incident leads to injury of construction worker.	Major	Remote	Inter-mediate	YES
3. Injury due to electrocution	Severe	Remote	Low	NO
4. Environmental damage due to loss of containment of hazardous and environmentally pollutant materials, e.g., during unloading or transfer.	Minor	Remote	Negligible	NO
5. Confined space entrapment, asphyxiation of operators and contractors during access to tunnel (e.g. due to flooding of tunnel).	Major	Remote	Inter-mediate	YES
6. Use of heavy machinery and vehicles or access track leads to environmental damage and possible bush fire from combustion engine igniting dry grass and brush on the track.	Severe	Remote	Low	NO
7. Fire or explosion incident during blow-out or purging of pipeline after construction or during commissioning.	Not credible			NO

Table 7 – Risk Profile, Operations Phase

Threat Analysis (initiating causes)	Conse-quences	Likeli-hood	Risk	ALARP Justification Required
8. Generic leaks or leaks due to mechanical damage or terrorism / sabotage resulting in injury to people nearby or destruction of adjacent property or environment. Possible explosion if ignition inside the tunnel.	Major	Remote	Inter-mediate	YES
9. Asphyxiation hazard or exposure to explosion overpressure or heat radiation by people accessing the tunnel (e.g. during maintenance), due to loss of containment of gas. If ignition source then possible explosion.	Major	Remote	Inter-mediate	YES
10. Natural event such as earthquake, land subsidence, cyclone, or waves, damages the tunnel and the feed gas pipeline resulting in injury to people nearby or destruction of adjacent property or environment. Possible explosion if ignition inside the tunnel.	Catast-rophic	Hypo-thetical	Inter-mediate	YES
11. Flooding of tunnel causes the pipeline to become buoyant and lead to hairline cracks and loss of integrity of the pipeline resulting in loss of containment and injury to people nearby, or to destruction of adjacent property or the environment	Major	Hypo-thetical	Low	NO
12. Injury to people whilst accessing the tunnel during inspection and maintenance routines due to electrocution, confined space / congestion, exposure to fumes due to inadequate ventilation, or slips, trips and falls.	Major	Remote	Inter-mediate	YES
13. Failure to properly purge the pipeline with inert gas prior to operational start-up, resulting in ignition of flammable gas and air present inside pipeline.	Major	Hypo-thetical	Low	NO

Table 8 – Risk Profile, Decommissioning Phase

Threat Analysis (initiating causes)	Conse-quences	Likeli-hood	Risk	ALARP Justification Required
14. Failure to properly purge the pipeline with inert gas prior to shut down and isolation, resulting in ignition of flammable gas and air present inside pipeline.	Major	Hypo-thetical	Low	NO
15. Decommissioning related incident leads to injury of construction worker.	Major	Remote	Inter-mediate	YES
16. Injury due to electrocution.	Severe	Remote	Low	NO

4.5 DEMONSTRATION OF ALARP

Seven threats or incidents were identified in the risk assessment as *Intermediate* risk and hence require demonstration of how ALARP principles are to be adhered to. Each of these threats and applicable controls are discussed in the table below. The numbering of the threats is as per Table 6, Table 7 and Table 8.

Threat Description	Location	Typical Controls
Construction Phase: 3. Injury to construction worker due to crushing, struck by falling equipment, dropped object, falls, slip, trip and falls, struck by moving equipment, manual handling hazards, working at heights, excessive heat or cold from objects, pressure burst, working in isolation. May lead to injury to construction personnel.	Entire length of feed gas pipeline (sections 1, 2 and 3)	**Prevention:** Documented in construction management plan, project inductions, heavy lift studies, life saving rules, manual handling, pre job safety meetings, manual handling safety training completed by all crews, approved scaffolding procedures, certified personnel and lifting equipment, lifting ops PTW and JSEA process, conducted prior to all potentially hazardous or non-routine operations, visits/audits by health, safety advisors, pre start inspection process to clear area during perforating activities, housekeeping or equivalent on all high pressure lines (including air lines), tag lines to be used on all suspended loads, inspection / register of harnesses and height safety equipment and anchor points. **Protection:** Machinery guarding, appropriate PPE worn, personal fall arrest equipment, wrist straps and lanyards to secure tools to be used at heights. **Emergency procedure:** Emergency procedures/drills, first aid trained personnel on site.

ALARP Analysis

Possible Alternative Mitigation:	Reason Not adopted:	ALARP Satisfied (Y/N)
No further mitigation identified.	N/A	**Yes**

Threat Description	Location	Typical Controls
Construction Phase: 6. Confined space to operators and contractors. May lead to asphyxiation, exposure to fumes and trapping hazards to personnel accessing the tunnel during construction activities.	Section 2	**Prevention:** PTW system specific for confined space, HSE audits and advice, appropriate equipment provided, specialised training including confined space entry, JSEA process) for all confined space entry. **Protection:** PPE. Escape respirators. **Emergency response:** Emergency response procedure. First aid trained personnel on site.

ALARP Analysis

Possible Alternative Mitigation:	Reason Not adopted:	ALARP Satisfied (Y/N)
No further mitigation identified.	N/A	**Yes**

Threat Description	Location	Typical Controls
Operations Phase: 8. Generic threats to the pipeline, including: - External interference - Construction defect / material failure - Corrosion - Valve gland nut leak or flange leak or maintenance failure at valves and scraper stations - Operational error causes pressure excursion leading to failure of the feed gas pipeline. May lead to loss of containment from the feed gas pipeline with possible ignition. Incident may lead to injury to people nearby, or to destruction of adjacent property or the environment. Possible explosion if ignition inside the tunnel.	Entire length of feed gas pipeline (sections 1, 2 and 3)	**Prevention:** Design the feed gas pipeline in accordance with AS2885.1. Use of high grade carbon steel; all materials and manufacturing methods to comply with recognised standards, practices and/or purchaser specifications. Acid sulphate surveys and appropriate management measures. Non-destructive testing (NDT) carried out on a regular basis. Fracture control plan and pipeline integrity plan to be prepared. Pipeline thickness resistant to mechanical damage; pipeline located within tunnel provides further protection. Pipeline coating (external and internal). Testing of all welds. Cathodic protection (on and off shore) and sacrificial anodes (off shore). Preventative maintenance and inspection programs, including use of intelligent pigging for planned periodic inspection. Operating procedures and safety management system. Security measures. **Detection:** Pressure instrumentation to transmit upset conditions to the control room. Control room manned 24 hours per day, all year. **Protection:** Remote activation of isolation valves. Further details provided below.

ALARP Analysis for Treat #8 - Generic threats to the pipeline:

The European Gas Pipeline Incident Data Group (EGIG) shows pipeline failure data, between 1970 and 2007, based on over 1,470,000 kilometre-years (Ref 8). Because of the similarities between the Australian Standard requirements and the requirements used in the European countries included in the incident statistics (Britain, Belgium, France, Netherlands, Ireland, Portugal, Finland, Sweden, Switzerland, Germany) this data set is seen as appropriate for the feed gas pipeline.

The following generic faults and mechanical interference threats are identified for the feed gas pipeline and discussed below:

- External interference
- Construction defect / material failure
- Corrosion
- Hot tap (on the wrong pipeline, by error)
- Valve gland nut leak or flange leak or maintenance failure at valves and scraper stations
- Operational error causes pressure excursion leading to failure of the feed gas pipeline

Threats and associated controls which could lead to a loss of pipeline integrity include:

External interference

The EGIG showed that external interference is historically the main cause of loss of gas and accounts for about 40% of all incidents leading to a release of gas. External interference threats comprise anything that may penetrate the ground in the vicinity of the pipeline, such as post hole augers, excavators, and boring machines. Controls applicable for the feed gas pipeline are:

- Separation by burial, including tunnel under boring under the Port Curtis. - Out of the total 7 km, the above ground sections will account for 1.9km in total. Most of the pipeline will be buried under a minimum cover of 750 mm to 900 mm (depending on the location class). Under the Port Curtis, the pipeline will be located in a tunnel of which the invert to the tunnel will be 35m below the depth of the seabed.
- Separation by exclusion - Restricted access/exclusion will be provided by locating all valve points and above ground sections within locked and fenced off areas. Further, the pipeline from the Arrow Surat Pipeline to the tunnel launch shaft and from the tunnel receival shaft on Hamilton Point to the LNG plant is predominantly within the Gladstone State Development Area Infrastructure Corridor, the State Infrastructure Corridor on Curtis Island and Arrow owned land or within the tunnel.
- Wall thickness – Resistance to penetration along the full length of the pipe is afforded by appropriate wall thickness. The high wall thickness makes the pipe less susceptible to external damage by mechanical equipment.
- Tunnel – The feed gas pipeline will be located within a concrete tunnel as it travels under Port Curtis. The depth of the pipeline will be approximately 35m below the bed of the harbour. Further, access to the tunnel is restricted via locked, security-fenced compounds surrounding each access shaft. These factors make external interference even less likely.
- Safety through design - The complete pipeline will be built out of submerged arc welded line pipe subject to full ultrasonic inspection along the weld seam together with hydrostatic testing in the pipe mill and all field welds will be subject to NDT with most also subject to field hydrostatic testing. The pipeline will have a high design safety factor

compared with operating conditions. All valves will be highly reliable and selected for this particular function.

- Signs – The location of the feed gas pipeline will be signposted along the length of the pipe route when it is not under Port Curtis. Sign posting requirements are detailed in AS2885.1.
- Periodic surveillance – In this location patrol or other (possibly automated) inspection of the feed gas pipeline will occur on a regular (e.g., weekly) schedule. The valve points will be leak tested regularly, and each valve is operated every month.
- Landowner and occupier liaison – Will be undertaken as per AS2885.1 and AS2885.3.
- Participation in One-Call Service – The feed gas pipeline will be registered with One-Call Service, which allows third parties to obtain accurate information on the location and nature of the buried service before undertaking activity above the pipeline.
- In the very unlikely event of damage to the pipeline, which causes a major leak, a sudden pressure drop would result in alarm initiation in the control room allowing automatic or remote activated emergency response.

Being lighter than air, coal seam gas disperses readily upwards, further reducing chances of ignition. Explosion is not credible in an unconfined situation. Further discussion on properties of the gas is provided in Appendix 2.

Valve stations are potentially more at risk of a loss of containment due to the presence of small bore attached piping, which is required for pressure tappings. Whilst these small-bore pipes are historically known to be more vulnerable to failure, they will be subject to regular and frequent inspections - possibly weekly in this area.

Construction defect / material failure

Construction defect or material failure is a known cause of failure of pipelines and accounts for approximately 15% of all incidents.

The feed gas pipeline will be subject to hydrostatic pressure testing prior to commissioning.

Further, inherent design safeguards will be provided by ensuring that the piping is manufactured from high tensile steel of known quality that is subjected to quality control inspections to ensure it meets an acceptable standard.

Corrosion

Corrosion accounts for approximately 15% of all historical incidents. The result of corrosion is mainly pinholes and cracks.

External corrosion will be minimised through use of upfront measures to remove occurrence of corrosive soils near the pipeline, such as Acid Sulfate Soils (ASS) and Potential Acid Sulfate Soil (PASS) surveys and appropriate treatment of backfill soils.

Further, the feed gas pipeline will be externally coated with fusion bond epoxy, or equivalent, and be cathodically protected when buried. Regular pipeline patrols or automated inspections will be undertaken to verify the continued effectiveness of the system.

A corrosion protection team will survey the feed gas pipeline on a regular basis to identify any areas where cathodic protection has become ineffective.

Internal corrosion is virtually absent with clean, dry hydrocarbon. The gas will be dehydrated and cleaned in one of Arrow Energy’s gas processing facilities at the gas field.

Hot tap by error

Hot tapping by error (i.e., hot-tapping as planned activity but on the wrong pipeline) is possible and has occurred previously (approximately 15% of all worldwide incidents).

Hot tapping is a highly specialised field in Australia and only very few, highly trained, groups can perform this task. Hot tapping on the feed gas pipeline would occur under tight control by Arrow Energy or its contractors and would involve site supervision, procedures and PTW. Further, there are no other pipelines in the vicinity of the pipeline in this location. This is not considered a credible event for the feed gas pipeline.

Valve gland nut leak or flange leak or maintenance failure at valves and scraper stations

Periodic surveillance will be carried out of the pipe and valve points. All valves will be operated periodically. All above ground valve sites will be fenced and secured to exclude the public. Minimisation or elimination of flanged joints subject to full line pressure, pending detailed design.

Operational error causes pressure excursion leading to failure of the feed gas pipeline

The feed gas pipeline, with associated pressure control at the upstream field Central Gas Production Facilities, will be designed such that over-pressurisation of the feed gas pipeline is not possible.

ALARP Justification

The consequences of a leak of the feed gas pipeline are very severe and hence the risk management strategy limiting this risk needs to be very robust. As discussed above, the strategy proposed for the feed gas pipeline is suitable for the level of consequences should a pipeline threat occur. The risk, while intermediate due to the consequences, can be regarded as ALARP.

ALARP Analysis for Treat #8 - Generic threats to the pipeline		
Possible Alternative Mitigation:	**Reason Not adopted:**	**ALARP Satisfied (Y/N)**
No further mitigation identified.	N/A	**Yes**

Threat Description	Location	Typical Controls
Operations Phase: 9. Loss of containment of flammable gas into tunnel, confining the flammable gas cloud. Initiating causes as per #8 above. If ignition source then possible explosion. May lead to asphyxiation hazard or exposure to explosion overpressure or heat radiation by people accessing the tunnel (e.g. during maintenance).	Section 2	**As per #8 above. In addition:** **Prevention:** Design for mitigating stress corrosion cracking. Operation and maintenance procedures. Minimise risk of induced voltage – possible need for electro-magnetic shielding. Earthing. Implement tunnel access restrictions. Eliminate or reduce to an absolute minimum the amount of electrical equipment inside the tunnel. For the electrical equipment that must remain within the tunnel, design to a correct hazardous classification (intrinsically safe) and maintain equipment to equal or exceed the requirements for such equipment. Install earthing, including redundant earthing. Minimise the risk of induced voltage, with the possible need for electromagnetic shielding.

ALARP Analysis

Possible Alternative Mitigation:	Reason Not adopted:	ALARP Satisfied (Y/N)
Design considerations include: - Determine appropriate monitoring systems. - Consider appropriate separation in design. - Consider automated inspection systems to minimise time spent in tunnel by personnel.	These measures will be evaluated during FEED.	Arrow Energy is in the process of designing the risk management strategy for the tunnel and only the concept design has been defined at this stage. This initial SMS has reviewed the proposed strategy and evaluated whether, with careful design, the tunnel can be operated at a risk level which, albeit of an *Intermediate l*evel, can be regarded as ALARP.

Threat Description	Location	Typical Controls
Operations Phase: 10. Loss of containment of flammable gas due to natural causes such as: - Earthquake - Land subsidence - Cyclones, major storms threatens the tunnel and hence the feed gas pipeline. May lead to injury to people nearby, or to destruction of adjacent property or the environment.	Entire length of feed gas pipeline (sections 1, 2 and 3)	The design of the tunnel and pipeline will incorporate seismic risks and the risks associated with cyclones, major storms and cyclonic activity. Steel pipelines have been shown to be very resistant to failure in these circumstances. The seismic risk to the pipeline will be assessed during FEED design. The pipeline will be located 35 metres under the sea-floor– threat from heavy waves is negligible.

ALARP Analysis

Possible Alternative Mitigation:	Reason Not adopted:	ALARP Satisfied (Y/N)
No further mitigation identified.	N/A	**Yes**

Threat Description	Location	Typical Controls
Operations Phase: 12. Threat to people whilst accessing the tunnel during inspection and maintenance routines due to: - electrocution - confined space / congestion - exposure to fumes due to inadequate ventilation - Slips, trips and falls. People could be exposed to hazards (electrical, airborne, mechanical) leading to injury or fatality	Section 2	Prevention: PTW system specific for confined space, HSE audits and advice, appropriate equipment provided, specialised training including confined space entry and diving training, JSEA process for all confined space entry and diving jobs. Electrical equipment and cables to be protected. Design and maintenance of ventilation system. HSE audits and advice will be provided. Electrical equipment and cables will be protected. Protection: PPE including escape respirators. Protection: Emergency response procedure. First aid trained personnel on site.

Threat Description	Location	Typical Controls	
ALARP Analysis			
Possible Alternative Mitigation:	**Reason Not adopted:**		**ALARP Satisfied (Y/N)**
Design considerations include: - Tunnel access restrictions to be implemented and many of the required inspection systems may be able to be automated to minimise time spent in tunnel by personnel. - Where tunnel entry is required, appropriate equipment and protective measures will be determined to minimise risks to personnel. - Appropriate monitoring systems will be determined. - Automated inspection systems will be evaluated. - Design and maintenance of the ventilation system will be optimised.	These measures will be evaluated during FEED.		Arrow Energy is in the process of designing the risk management strategy for the tunnel and only the concept design has been defined at this stage. This initial SMS has reviewed the proposed strategy and evaluated whether, with careful design, the tunnel can be operated at a risk level which, albeit of an *Intermediate l*evel, can be regarded as ALARP.

Threat Description	Location	Typical Controls
Decommissioning Phase: 15. Injury to decommissioning worker due to failure of manual handling procedure or equipment. Incident may lead to pressure burst and injury to personnel. Crushing, struck by falling or moving equipment, dropped object, slip, trip and falls, manual handling hazards, excessive heat or cold.	Entire length of feed gas pipeline (sections 1, 2 and 3)	**Prevention**: Documented in decommissioning management plan, training and supervision including induction, training, supervision pre job safety meetings, manual handling safety training completed by all crews, approved scaffolding procedures, certified personnel and lifting equipment, lifting ops, PTW including requirements working at heights and suspended loads, JSEA process to be conducted prior to all potentially hazardous or non-routine operations, visits/audits by health, safety advisors, pre start inspection, process to clear area during perforating activities, housekeeping. Tie-downs or equivalent on all high pressure lines (including air lines), tag lines to be used on all suspended loads, inspection / register of harnesses and height safety equipment and anchor points. **Protection**: Machinery guarding, appropriate PPE worn, personal fall arrest equipment, wrist straps and lanyards to secure tools to be used at heights. **Emergency procedure**: Emergency procedures/drills, first aid trained personnel on site.

ALARP Analysis

Possible Alternative Mitigation:	Reason Not adopted:	ALARP Satisfied (Y/N)
No further mitigation identified.	N/A	**Yes**

5 "ALL CONTROLS FAIL"

Clause 2.3.6 of AS2885.1-2007 requires a test of the rigour of the safety management study by considering an event where all threat controls fail and the pipeline is damaged. However the code recommends this occur towards the end of detailed design when there is sufficient knowledge of the controls proposed

The undetected corrosion of the feed gas pipeline leading to a rupture was considered to be the worst conceivable event which could occur if all the threat mitigation measures failed (a hypothetical occurrence).

Should this worst case scenario occur, then the consequence distance is the measurement length of full bore rupture, in Section 4.3.2, as follows:

- Approximate distance to 4.7kW/m^2: 1.5km (for a 1,220 mm diameter pipeline) or 1.8km (for a 1,422mm diameter pipeline);
- Approximate distance to 12.6kW/m^2: 0.9km (for a 1,220 mm diameter pipeline) or 1.1km (for a 1,422mm diameter pipeline);

The risk ranking was no higher than *Intermediate* for this event and provides reassurance that:

- The pipeline has a high level of pipeline design safety;
- The controls of the pipeline are of a very high standard;
- The safety management study did not ignore any serious threats.

6 CONCLUSIONS AND RECOMMENDATIONS

A risk profile for the feed gas pipeline developed in this SMS shows treated risk levels to be either *Low* or *Intermediate.*

The 16 threats identified in the study were classified and are summarised in Table 9 below.

Table 10 – Risk Classification for Identified Threats

Type	No of Threats
Identified as NON CREDIBLE	1
Threats ranked LOW or NEGLIGIBLE	8
Threats ranked INTERMEDIATE	7
Not accepted, ranked as HIGH or above	0

No threats were ranked High, and hence there were no critical risk management actions. Eight threats were classified as Intermediate.

Five of the *Intermediate* risks were readily considered to be ALARP due to the risk reduction measures already designed and specified.

The design of the remaining two *Intermediate* risks is still in its conceptual phase (i.e. the risk of creating a confined flammable vapour cloud inside the tunnel with subsequent ignition and explosion, and the risk of exposure of people to flammable and asphyxiant gases inside the tunnel). For these risks, no conclusive ALARP justification can be made. However, the preliminary SMS justified the risk associated with the conceptual design and proposed risk reduction measures of these two scenarios is ALARP.

The design of the feed gas pipeline is conservative when AS2885.1 is followed.

This safety management study has identified the following recommendations for the feed gas pipeline and associated mitigating strategies:

Recommendation 1: Determine emergency response to a major incident associated with the pipeline (e.g., in case of a major failure of the pipeline), including possible need for remote activated and automatic isolation and flaring.

Recommendation 2: Develop construction and commissioning safety management plans.

Recommendation 3: Conduct HAZOP (hazard and operability) studies towards the end of FEED design and if required updated at detailed design.

Recommendation 4: Establish trips and alarm philosophy as well as venting and relief requirements during detailed design.

Recommendation 5: Develop emergency plans for the construction, operation and decommission of the feed gas pipeline.

Recommendation 6: Progress the design of the required risk control measures to enable justification of the tunnel concept against ALARP risk principles. This is both to prevent ignition of flammable gases and to safeguard personnel during inspection and maintenance.

Recommendation 7: If required, undertake a seismic study of the pipeline route, particularly covering the pipeline vulnerability as it traverses Port Curtis.

Recommendation 8: Review the available SI data and conduct further investigations where necessary to demonstrate that land subsidence is not a risk to the integrity of the pipeline.

Recommendation 9: Design of the pipeline and tunnel to ensure that flooding of the tunnel, and the forces exercised on the pipeline in case of flooding, is not a risk to the integrity of the pipeline.

Recommendation 10: Conduct safety management study (SMS) workshops covering the feed gas pipeline at the end of the FEED phase, and a final detailed SMS, to be completed at the end of detailed design.

Recommendation 11: Prepare a safety and operating plan (SAOP) in accordance with AS2885 requirements. The SAOP should specify the required inspections and leak surveys to be carried out for the pipeline. Audit adherence to the SAOP at approved intervals by independent auditor(s).

Recommendation 12: Develop and implement procedures for blow-out and purging of the feed gas pipeline.

Recommendation 13: Construct, commission, operate and decommission the pipeline in accordance with safety and operating plans and construction/demolition management plans.

Recommendation 14: X-ray all feedgas pipeline welds (100%).

Recommendation 15: Assess the need for inert gas to pressurise the empty space within the tunnel during the detailed design stage.

Appendix 1

Detailed Preliminary Safety Management Study Results

Preliminary Safety Management Study in Accordance With AS2885.1 of Arrow Energy's LNG Project: Feed Gas Pipeline, Gladstone, Queensland

Appendix 1 – Detailed Preliminary SMS Results

Location	Threat Analysis (initiating causes)	Failure Analysis (possible consequences and effects)	Typical Controls	Threat Credible (YES/ NO)	Conse-quence	Likeli-hood	Risk
Construction and Commissioning							
Entire length of feed gas pipeline (sections 1, 2 and 3)	1. Release of flammable or combustible material (e.g. fuel used for construction) due to damage to storage vessels, hoses or pipes.	Possible environmental pollution if uncontained. Fire potential if presence of ignition source involving flammable or combustible liquids. Incident may lead to injury to people nearby, or to destruction of adjacent property or the environment.	**Prevention:** Liquid flammable and combustible materials used during construction and commissioning managed using AS1940 requirements. Documented in construction management plan. Personnel trained in hazardous materials handling procedures and safeguards. Correct PPE. **Protection:** Emergency response plan and training.	Yes	Major (Safety and Environmental)	Hypothetical	Low

Location	Threat Analysis (initiating causes)	Failure Analysis (possible consequences and effects)	Typical Controls	Threat Credible (YES/ NO)	Conse-quence	Likeli-hood	Risk
Entire length of feed gas pipeline (sections 1, 2 and 3)	2. Injury to construction worker due to crushing, struck by falling equipment, dropped object, falls, slip, trip and falls, struck by moving equipment, manual handling hazards, working at heights, excessive heat or cold from objects, pressure burst, working in isolation.	Injury to construction personnel.	**Prevention:** Documented in construction management plan, training and supervision including induction, training, supervision pre job safety meetings, manual handling safety training completed by all crews, approved scaffolding procedures, certified personnel and lifting equipment, lifting ops, PTW and *Lifesaving rules* for working at heights and suspended loads, JSEA process to be conducted prior to all potentially hazardous or non-routine operations, visits/audits by health, safety advisors, pre start inspection process to clear area during perforating activities, housekeeping or equivalent on all high pressure lines (including air lines), tag lines to be used on all suspended loads, inspection / register of harnesses and height safety equipment and anchor points. **Protection:** Machinery guarding, appropriate PPE worn, personal fall arrest equipment, wrist straps and lanyards to secure tools to be used at heights. **Emergency procedure:** Emergency procedures/drills, first aid trained personnel on site.	Yes	Major (Safety)	Remote	Intermediate
Entire length of feed gas pipeline (sections 1, 2 and 3)	3. Electrocution from electrical power line impacts, third party equipment impacts, non-intrinsically safe equipment, lightning, battery fire and explosion or battery storage incident.	Injury to personnel.	**Prevention:** Qualified electrician at the site, trained and qualified personnel, planned maintenance of electrical equipment, correct grounding of electrical circuit, Health and safety audit. PTW including JSEA process. **Protection:** Earth leakage protection. Earthing cables used. **Emergency procedure:** Emergency response procedure. First aid trained personnel on site.	Yes	Severe (Safety)	Remote	Low

Location	Threat Analysis (initiating causes)	Failure Analysis (possible consequences and effects)	Typical Controls	Threat Credible (YES/ NO)	Conse-quence	Likeli-hood	Risk
Section 1 and Section 3	4. Loss of containment from storage or during handling of hazardous and environmentally pollutant materials, e.g., during unloading or transfer.	Local environmental pollution and injury to personnel due to failure to contain a loss of containment of environmentally pollutant materials.	**Prevention:** Procedures developed for occupations that work with hazardous and environmentally pollutant materials, training of personnel, audits and inspections, suitable storage facilities available following code requirements, Material Safety Data Sheets (MSDS) available, covered in the Induction, legislative requirement for dangerous goods transportation, dedicated cargo handling and storage area, that is cleared of all personnel, signs, health and safety advisers regularly audit. **Emergency response:** Spill kits, personnel trained in spill response on site, emergency response plan and local hazardous materials response plan in the event of a spill.	Yes	Minor (Safety and Environmental)	Remote	Low
Section 2	5. Confined space hazards to operators and contractors.	Asphyxiation and trapping hazards to personnel accessing the tunnel during construction activities.	**Prevention:** PTW system specific for confined space, HSE audits and advice, appropriate equipment provided, specialised training including confined space entry and diving training, JSEA process for all confined space entry work. Use of Remote Operated Vehicles where possible instead of diving. **Protection:** PPE. Escape respirators. **Emergency response:** Emergency response procedure. First aid trained personnel on site.	Yes	Major (Safety)	Remote	Intermediate
Section 1 and Section 2	6. Use of heavy machinery and vehicles or access track.	Potential for erosion, dust and weed spreading. Access by vehicles on the access track (from combustion engine on vehicle) may cause bushfire.	**Prevention:** Track selection to avoid sensitive environmental areas. Track maintenance in accordance with procedure. Speed limits (minimises dust generation and deterioration). Use of designated track only. **Protection:** Fire extinguisher in vehicle.	Yes	Severe (Environmental)	Remote	Low

Location	Threat Analysis (initiating causes)	Failure Analysis (possible consequences and effects)	Typical Controls	Threat Credible (YES/ NO)	Conse-quence	Likeli-hood	Risk
Entire length of feed gas pipeline (sections 1, 2 and 3)	7. Ignition of flammable gas during blow-out of construction material from pipeline using CSG, or purging of the pipeline prior to start-up.	Possible fire or explosion. Incident may lead to injury to people nearby, or to destruction of adjacent property or the environment.	**Prevention:** Procedures for blow-out and purging. Permit to Work (PTW), including hot work permits and JSEA process. Construction site training and induction. Health and safety performance monitoring, inspections and audits by trained Arrow Energy personnel or contractors. Construction and commissioning carried out as per Safety and Operating Plans and Permit to Work. Supervision, appropriate tools, control of ignition sources. Use of inert gas (usually nitrogen) for blow-out and purging, ensuring that the air and CSG cannot mix. Commissioning procedures. **Protection:** Personal Protective Equipment (PPE) for on-site workers. Construction camp is located well outside the measurement length.	No			

Location	Threat Analysis (initiating causes)	Failure Analysis (possible consequences and effects)	Typical Controls	Threat Credible (YES/ NO)	Conse-quence	Likeli-hood	Risk
Operation							
Entire length of feed gas pipeline (sections 1, 2 and 3)	8. Generic threats to the pipeline, including: - Corrosion. - Fault in design, materials, manufacturing, installation, maintenance. - Mechanical damage of pipeline or pipeline coating. - Terrorism, sabotage, security event.	Loss of containment from the feed gas pipeline with possible ignition. Incident may lead to injury to people nearby, or to destruction of adjacent property or the environment. Possible explosion if ignition inside the tunnel.	**Prevention:** Design the feed gas pipeline in accordance with AS2885.1. Use of high grade carbon steel; all materials and manufacturing methods to comply with recognised standards, practices and/or purchaser specifications. Non-destructive testing (NDT) carried out on a regular basis. Fracture control plan and pipeline integrity plan to be prepared. Pipeline thickness resistant to mechanical damage; pipeline located within tunnel provides further protection. Pipeline coating (external and internal). Testing of all welds. Cathodic protection (on and off shore) and sacrificial anodes (off shore). Preventative maintenance and inspection programs, including use of intelligent pigging for planned periodic inspection. Operating procedures and safety management system. Security measures complying with Major Hazard Facilities (MHF) requirements. **Detection:** Pressure instrumentation to transmit upset conditions to the control room. Control room manned 24 hours per day, all year. **Protection:** Remote activation of isolation valves.	Yes	Major (Safety)	Remote	Intermediate

Location	Threat Analysis (initiating causes)	Failure Analysis (possible consequences and effects)	Typical Controls	Threat Credible (YES/ NO)	Conse-quence	Likeli-hood	Risk
Section 2	9. Loss of containment of gas into tunnel, confining the flammable gas cloud. Initiating causes as per #10 above. If ignition source then possible explosion.	Asphyxiation hazard or exposure to explosion overpressure or heat radiation by people accessing the tunnel (e.g. during maintenance).	**As per #10 above. In addition:** **Prevention:** Design for mitigating stress corrosion cracking. Operation and maintenance procedures. Design to minimise electrical equipment and potential ignition sources in electrical equipment. Assess the need to use inert gas to minimise risk of ignition. Minimise risk of induced voltage – possible need for electro-magnetic shielding. Earthing. Implement tunnel access restrictions. Determine appropriate monitoring systems. Consider appropriate separation in design. Consider automated inspection systems to minimise time spent in tunnel by personnel. Analysis of Lowland Acid Sulfate Soils (ASS) and Potential Acid Sulfate Soils (PASS).	Yes	**Major (Safety)**	**Remote**	**Intermediate**
Entire length of feed gas pipeline (sections 1, 2 and 3)	10. Loss of containment of flammable gas due to natural causes such as: - Earthquake - Land subsidence - Cyclones, major storms, heavy waves threatens the tunnel and hence the feed gas pipeline	Incident may lead to injury to people nearby, or to destruction of adjacent property or the environment.	**Prevention:** Design the tunnel and pipeline to incorporate seismic risks and risks from cyclones, major storms. Pipeline located 35 metres under water – threat from heavy waves is negligible.	Yes	**Catastrophic (Safety)**	**Hypothetical**	**Intermediate**

Location	Threat Analysis (initiating causes)	Failure Analysis (possible consequences and effects)	Typical Controls	Threat Credible (YES/ NO)	Conse-quence	Likeli-hood	Risk
Section 2	11. Flooding of the tunnel	May cause the pipeline to become buoyant and lead to hairline cracks and loss of integrity of the pipeline. Incident may lead to injury to people nearby, or to destruction of adjacent property or the environment.	Feed gas pipeline may need to be clamped or otherwise secured within the tunnel to ensure it does not become buoyant in case of flooding of the tunnel. Application of such technical solutions will be determined during the design process and will be subject to formal risk assessment.	Yes	**Major (Safety and Environmental)**	**Hypothetical**	**Low**
Section 2	12. Threat to people whilst accessing the tunnel during inspection and maintenance routines due to: - electrocution - confined space / congestion - exposure to fumes due to inadequate ventilation - Slips, trips and falls	People could be exposed to hazards (electrical, airborne, mechanical) leading to injury or fatality	**Prevention:** PTW system specific for confined space, HSE audits and advice, appropriate equipment provided, specialised training including confined space entry and diving training, JSEA process for all confined space entry and diving jobs. Time required to access tunnel to be minimised through use of fast change over systems. Determine appropriate monitoring systems. Consider automated inspection systems. Electrical equipment and cables to be protected. Design and maintenance of ventilation system. **Protection:** PPE including escape respirators. **Protection:** Emergency response procedure. First aid trained personnel on site.	Yes	**Major (Safety)**	**Remote**	**Intermediate**

Location	Threat Analysis (initiating causes)	Failure Analysis (possible consequences and effects)	Typical Controls	Threat Credible (YES/ NO)	Conse-quence	Likeli-hood	Risk
Entire length of feed gas pipeline (sections 1, 2 and 3)	13. Failure to properly purge the pipeline with inert gas prior to operational start-up, resulting in ignition of flammable gas and air present inside pipeline.	Incident may lead to injury to people nearby, or to destruction of adjacent property or the environment.	**Prevention:** This scenario is only theoretically possible during start-up, shut-down and maintenance operations. Start-up procedures and maintenance procedures will include requirements for purging Air from the pipeline including continuous monitoring of the composition of the air/gas stream at the vent and establishment and enforcement of an exclusion zone, or purging with an inert gas when the assessed risk requires this additional control. Gas will be vented through the LNG plant flare system.	Yes	Major (Safety and Environmental)	Hypothetical	Low
Decommissioning							
Entire length of feed gas pipeline (sections 1, 2 and 3)	14. Failure to properly purge the pipeline with inert gas prior to shut down and isolation, resulting in ignition of flammable gas and air present inside pipeline.	Possible fire or explosion. Incident may lead to injury, destruction of property and damage to the environment.	**Prevention:** Procedures for purging gas from the pipeline with an inert gas will include continuous monitoring of the composition of the air/gas stream at the vent and establishment and enforcement of an exclusion zone. Gas will be vented through the LNG plant flare system. Permit to Work (PTW), including hot work permits and JSEA process. Construction site training and induction. Health and safety performance monitoring, inspections and audits by trained Arrow Energy personnel or contractors. Construction and commissioning carried out as per safety and operating plans and Permit to Work. Supervision, appropriate tools, control of ignition sources. **Protection:** Appropriate PPE worn.	Yes	Major (Safety and Environmental)	Hypothetical	Low

Location	Threat Analysis (initiating causes)	Failure Analysis (possible consequences and effects)	Typical Controls	Threat Credible (YES/ NO)	Conse-quence	Likeli-hood	Risk
Entire length of feed gas pipeline (sections 1, 2 and 3)	15. Injury to decommissioning worker due to failure of manual handling procedure or equipment.	Pressure burst and injury to personnel. Crushing, struck by falling or moving equipment, dropped object, slip, trip and falls, manual handling hazards, excessive heat or cold.	**Prevention**: Documented in decommissioning management plan, training and supervision including induction, training, supervision pre job safety meetings, manual handling safety training completed by all crews, approved scaffolding procedures, certified personnel and lifting equipment, lifting ops, PTW (lifesaving rules for working at heights and suspended loads), JSEA process to be conducted prior to all potentially hazardous or non-routine operations, visits/audits by health, safety advisors, pre start inspection, process to clear area during perforating activities, housekeeping. Tie-downs or equivalent on all high pressure lines (including air lines), tag lines to be used on all suspended loads, inspection / register of harnesses and height safety equipment and anchor points. **Protection**: Machinery guarding, appropriate PPE worn, personal fall arrest equipment, wrist straps and lanyards to secure tools to be used at heights. **Emergency procedure**: Emergency procedures/drills, first aid trained personnel on site.	Yes	Major (Safety)	Remote	Intermediate
Entire length of feed gas pipeline (sections 1, 2 and 3)	16. Injury due to electrocution	Electrocution from electrical power line impacts, third party equipment impacts, non-intrinsically safe equipment, lightning, battery fire and explosion or battery storage incident.	**Prevention**: Qualified electrician at the site, trained and qualified personnel, planned maintenance of electrical equipment, correct grounding of electrical circuit, health and safety audit. PTW including JSEA process. **Protection**: Earth leakage protection. Earthing cables used. **Emergency procedure**: Emergency response procedure. First aid trained personnel on site.	Yes	Severe (Safety)	Remote	Low

Appendix 2

Properties of Hazardous Materials

Preliminary Safety Management Study in Accordance With AS2885.1 of Arrow Energy's LNG Project: Feed Gas Pipeline, Gladstone, Queensland

Appendix 2 - Properties of Hazardous Materials

The composition of coal seam gas is predominantly methane gas (about 95 to 98%), with some nitrogen and carbon dioxide. The gas may include very small quantities of ethane, propane and butane (less than 0.05%).

It is a buoyant, flammable gas which is held under pressure. It is lighter than air and, on release into the atmosphere, tends to rise rapidly and disperse to below hazardous concentrations unless it encounters an ignition source.

Vapours are in the flammability range when ratio of coal seam gas to oxygen is between approximately 5.5 and 14% flammable gas.

Fire and/or vapour cloud explosion is only possible with a concurrent source of ignition.

Ignition at the point of release is possible and natural gas would burn as a jet (or torch) flame. Delayed ignition could lead to a flash fire. Vapour cloud explosion may occur in case of accumulation and subsequent ignition of a large flammable gas cloud.

Coal seam gas is non-toxic, posing only an asphyxiation hazard. As it is buoyant, any release from the pipeline, in the open, would not present an asphyxiation hazard. Releases from the pipeline inside the tunnel poses an asphyxiation hazard to maintenance workers and other people accessing the tunnel. The off-site risk associated with asphyxiation from coal seam gas is minimal.

Locally, for site personnel, the pressure of compressed gas may be hazardous in case of an uncontrolled release. Pressure hazards, while important to people working at the site, do not have implications beyond the immediate location of the release. Therefore, the risk associated with non-ignited compressed gas does not form part of the scope of this assessment. This potential risk would need to be closely managed through Permit to Work and Job Safety and Environment Analysis process.

Appendix 3

TOR Cross Referencing Table

Preliminary Safety Management Study in Accordance With AS2885.1 of Arrow Energy's LNG Project: Feed Gas Pipeline, Gladstone, Queensland

Appendix 3 – TOR Cross Referencing Table

Hazard and Risk Cross-reference with the Co-ordinator General's Terms of Reference: Arrow LNG Plant		
TOR Section	**Terms of Reference Requirement**	**Section**
6.1.1	A risk assessment in accordance with Australia/New Zealand Standard AS/NZS 2885 Gas and Liquid Petroleum Pipelines should be conducted on the gas transmission pipeline from Gladstone City Gate to the LNG plant on Curtis Island.	4
	The results of the location analysis	4.1
	and threat analysis	4.2
	and calculation of 'measurement lengths' should be presented together with	4.3.2
	management strategies which will be employed to deliver the safety principles of the standard that require risks to be reduced to as low as reasonably practical, low or negligible.	4.3 4.4 4.5 Appendix 1

7 REFERENCES

1 *Terms of reference for an environmental impact statement, Shell Australia LNG Project*, The Coordinator-General, The Queensland Government, January 2010

2 *Pipelines – Gas and Liquid Petroleum*, Part 1 – *Design and Construction, 2007* Australian Standard AS2885.1-2007,

3 *Terms of reference for an environmental impact statement, Shell Australia LNG Project*, The Coordinator-General, The Queensland Government, January 2010

4 *Pipelines – Gas and Liquid Petroleum*, Part 1 – *Design and Construction, 2007*, Australian Standard AS2885.1-2007,

5 *Preliminary Hazards and Risk Assessment for the Arrow Energy Australia LNG Facility*, Nilsson K, Planager Pty Ltd, November 2011

6 *Arrow Energy LNG Project Conceptual HAZID for Routing Power Transmission Media and Feed Gas Pipeline through Tunnel*, Chynoweth S, Shell Global Solutions (Malaysia) Sdn Bhd – Projects and Technology, 24 February 2011

7 *Guide for Pressure-Relieving and Depressuring Systems,* American Petroleum Institute Report 521, 4th Edition, 1997

8 *7th Report of the European Gas Pipeline Incident Data Group (7th EGIG Report 1970-2007)*; European Group of Pipeline Incident Data