PRELIMINARY HAZARD AND RISK ASSESSMENT OF ARROW ENERGY'S SURAT GAS PROJECT, QLD

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EXECUTIVE SUMMARY

E1 Overview

Preliminary hazard and risk assessment of the Arrow Energy Pty Ltd (Arrow) proposed coal seam gas (CSG) development in the Surat Basin, Queensland, has not identified any risks to people safety or to property from accidental releases of hazardous material associated with the proposed development beyond acceptable levels or that exceed legislative safety and risk guidelines.

From the point of view of adherence to generally accepted risk criteria, the proposed facilities which form part of this development can be developed within the Surat basin alongside existing landuse and possible future development.

The gas facilities will produce, transport, process and handle flammable coal seam gas. The potential for accidents is understood and the design of the plants and facilities will emphasise minimisation of the probability of an accident happening and mitigating an accident if it occurs. Arrow is committed to reducing the health and safety risks to public, employees and contractors to levels that are as low as reasonably practicable (ALARP).

The construction, commissioning, operation and decommissioning of the facilities will be subject to a rigorous management process, safeguarding delivery and operation in a manner that minimises the risk to workers and the community.

The safety, efficiency and stability of the proposed facilities will be achieved through the use of high level safety systems, regular preventative maintenance programs, detection and protective measures. Security measures will include security patrols, protective enclosures, lighting and monitoring equipment.

E2 Background

Arrow Energy Pty Ltd (Arrow) is an integrated energy company with interests in coal seam gas field developments, pipeline infrastructure, electricity generation and proposed liquefied natural gas (LNG) projects.

Arrow proposes expansion of its coal seam gas operations in the Surat Basin through the Surat Gas Project. The need for the project arises from the growing demand for gas in the domestic market and global demand and the associated expansion of LNG export markets.

The project development area covers approximately 8,600 km^2 and is located approximately 160 km west of Brisbane in Queensland's Surat Basin. The project development area extends from the township of Wandoan in the north towards Goondiwindi in the south, in an arc adjacent to Dalby. Townships within or in close proximity to the project development area include (but are not limited to) Wandoan, Chinchilla, Kogan, Dalby, Cecil Plains, Millmerran, Miles and Goondiwindi. Project infrastructure, including coal seam gas production wells and production facilities (including both water treatment and power generation facilities where applicable), will be located throughout the project development area, but not inside towns.

Infrastructure for the project is expected to comprise:

- Approximately 7,500 production wells (with a peak drilling rate of approximately 400 wells per year).
- Low and medium pressure gas gathering lines to transport gas from the production wells to production facilities.

- High pressure gas pipelines to transport gas from central gas processing and integrated processing facilities to the sales gas pipeline.
- Water gathering lines (located in a common trench with the gas gathering lines) to transport coal seam water from production wells to transfer, treatment and storage facilities.
- Approximately 18 compression and processing facilities across the project development area expected to comprise of six of each of the following:
  - Field compression facilities;
  - Central gas processing facilities;
  - Integrated processing facilities.
- A combination of gas powered electricity generation equipment, that will be co-located with production facilities, and/or electricity transmission infrastructure that may draw electricity from the grid (via third party substations).

No hydraulic fracturing (or *fraccing)* will occur in the Surat Gas Project development area. The depth and permeability of the coal makes the process unnecessary.

This Preliminary Hazard and Risk Assessment (PHA) has been prepared as part of the project approval process as per the requirements by the Queensland Government and the Commonwealth Government. The aim of the PHA is to determine the risk to people and property from potentially significant incidents associated with the development, from their construction, normal operation and maintenance and finally thorough decommissioning. The following facilities form part of the development:

- Gas wells;
- Gathering lines (linking wells to compression and water treatment facilities);
- Field Compression Facilities (FCF);
- Central Gas Processing Facilities (CGPF);
- Integrated Processing Facilities (IPF).

The risks associated with the above facilities, is assessed from their installation and onwards, as follows:

- Design and installation (including drilling and casing of wells, digging and trenching pipelines, constructing plant and equipment, and bringing the equipment into production);
- Normal operation and maintenance and;
- Decommissioning and rehabilitation.

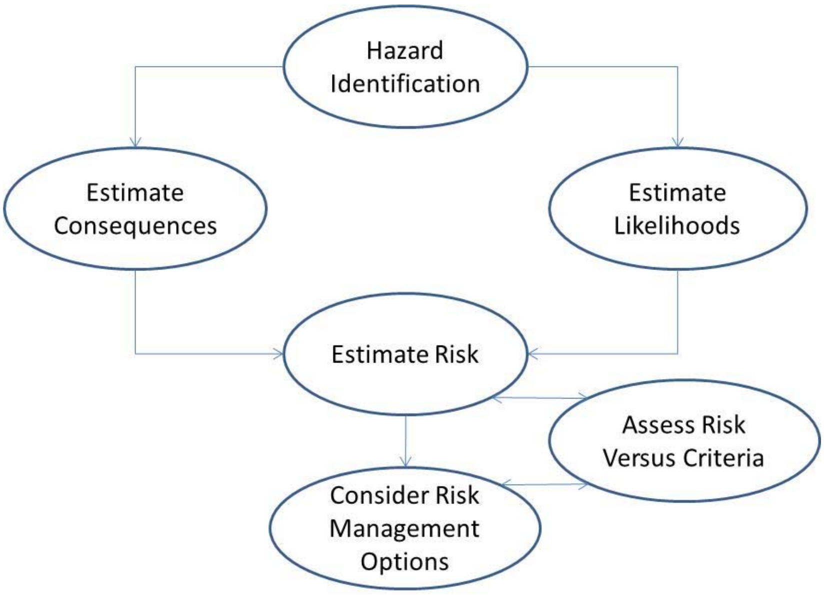
The types of risks considered in this PHA are:

- Risk of human injury or fatality;
- Risk of propagation of an incident to neighbouring facilities or damage to property.

E3 Study Methodology

A general outline of the risk assessment process is conceptually depicted in Figure E1 below.

Figure E1 – General Risk Analysis Process



The methodology used attempts to take account of all possible significant hazardous situations that may arise, particularly those that have the potential to cause an off-site risk and to qualify and, where possible quantify, these by estimating their possible consequences and likelihood.

The risk of an event is a combination of the probability of an outcome (such as injury, death or propagation to neighbouring industrial facilities) with the likelihood of the event. In order to assess the merit of the proposed development, it is necessary to estimate the risk at a number of locations so that the overall impact can be assessed.

The risk for each event is estimated according to:

Risk = Consequence x Likelihood

In the quantitative portion of this risk assessment, the risk from each event is combined to develop risk transects and risk contours. The calculated risk results can then be compared with the risk criteria for landuse planning as used in Queensland, and the Hazard and Risk Framework Approach can be determined (as presented in Table E1 below).

No formal risk assessment guidelines or risk criteria have been published in Queensland as yet. The guidelines developed by the NSW Department of Planning in their *Hazardous Industry Planning Advisory Paper* (HIPAP) number 6 – *Guidelines for Risk* Analysis and HIPAP No 4 - *Risk Criteria for Land Use Planning* follow internationally recognised practices for hazard and risk assessments and are commonly adopted for these types of assessments in Queensland and elsewhere in Australia and have therefore been adopted for the present PHA.

E4 Results

E4.1 Establishment of Constraints

With the dispersed population found in the Surat Gas Project development area it is possible to develop the area for petroleum exploration and operation whilst ensuring safety of people living and working in the area and whilst minimising the risk of damage to residences or local business from adverse effects of this development. This would be achieved by avoiding towns and maintaining adequate buffer zones between the petroleum activities and the local population.

At this early stage of the project there is an inherent uncertainty associated with the location and placement of any of the infrastructure.

Constraints are therefore required to be developed for a range of different perspectives.

These constraints describe the minimum buffer zones between the infrastructure which form part of this development and existing and future landuses in that area.

In the case of this PHA, the constraints have been developed in terms of hazards and risks associated with the construction, operation and decommissioning of the infrastructure. The buffer zones are presented in Table E1 below.

For well heads, the calculated buffer zone is significantly smaller than that proposed by Arrow, through their internal management practices. In this case, the internal Arrow buffer zone is presented in Table E1.

Table E1 – Hazard and Risk Framework Approach

Constraint	Applicable Framework	Project Activity		
		Production and operation of wells	Gathering lines	CGPF, IPFs and FCFs
No go	**National parks:** No IPFs (including CGPFs, production facilities, water treatment facilities, dams or power generation facilities) within 1 km of Wondal Range National Park and Bendidee National Park. No production wells within 100 m of the Wondul Range National Park and Bendidee National Park. No high pressure gas pipelines or gathering lines within 100 m of the Wondul Range National Park and Bendidee National Park.	NO	NO	NO
No go	**Within towns and townships:** No activity is permitted. Design controls will be applied to ensure all staff and contractors comply with the constraint. A number of towns and built up areas fall within Arrow's petroleum tenures, either in whole or in part. This includes the towns of: Columboola, Chinchilla, Brigalow, Warra, Macalister, Dalby, Cecil Plains and Millmerran.	NO	NO	NO

Constraint	Applicable Framework	Project Activity		
		Production and operation of wells	**Gathering lines**	**CGPF, IPFs and FCFs**
No go	***Sensitive Development***, including schools, hospitals, prisons, day cares, aged care facilities: Site-specific assessment is required with respect to any existing or proposed sensitive development in the area. This should include formal and documented discussions with landholders and with Local Councils. Standard operating procedures in conjunction with site-specific controls will be developed to minimise impact to acceptable levels. Emergency conditions should be considered and mitigated. • No gas wells within the Arrow minimum 200 m buffer distance (distance measured from the well head to the boundary of the sensitive development). • No FCFs within the Arrow minimum 200 m buffer distance (distance measured from the outer edge of the compressors to the boundary of the sensitive development). • No CGPF or IPFs within 290m of sensitive development (distance measured from the outer edge of the compressors the boundary of the sensitive development). • No large diameter (greater than 100 mm) low pressure gas gathering lines within 10 m of sensitive development (distance measured from the centreline of the pipeline to the boundary of the sensitive development). Low pressure gas gathering lines with internal diameter equal to or less than 100 mm can be placed adjacent to sensitive development provided the easement is maintained. • No large diameter (greater than 100 mm) medium pressure gas gathering lines within 60 m of sensitive development (distance measured from the centreline of the pipeline to the boundary of the sensitive development). Medium pressure gas gathering lines with internal diameter equal to or less than 100 mm or with large diameter and equipped with a concrete slab on top can be placed adjacent to sensitive development provided the easement is maintained. • High pressure gas pipelines: Design requirements for T2 *High Density Residential* will apply for pipelines installed within the measurement length of 864 metres of a sensitive development.	NO	NO	NO

Constraint	Applicable Framework	Project Activity		
		Production and operation of wells	**Gathering lines**	**CGPF, IPFs and FCFs**
Moderate	***Near residential development*** Site-specific assessment is required with respect to any existing or proposed residential development in the area. This should include formal and documented discussions with landholders and with Local Councils. Standard operating procedures in conjunction with site-specific controls will be developed to minimise impact to acceptable levels. Emergency conditions should be considered and mitigated. • No gas wells within the Arrow minimum 200 m buffer distance (distance measured from the well head to the home or resident). • No FCFs within the Arrow minimum 200 m buffer distance (distance measured from the well head to the home or resident). • CGPF and IPFs may be developed in areas where the buffer zone from the outer edge of the compressor to the boundary of residential development exceeds 210 m. • Gathering lines (low and medium pressure) may be established in areas where the buffer zone from the centre of the gathering line to the boundary of residential development exceeds 8 m, provided the easement is maintained and provided the location, threat and risk analysis provide acceptable risk levels. • High pressure gas pipelines: The design requirements for T1 *Residential* or T2 *High Density Residential* will apply for pipelines installed within the measurement length of 864 metres of a residential development.	YES	YES	YES

Constraint	Applicable Framework	Project Activity		
		Production and operation of wells	**Gathering lines**	**CGPF, IPFs and FCFs**
Moderate	**Development next to active open space, business or industry:** Site-specific assessment is required with respect to any existing or proposed active open space, business or industry development in the area, including formal and documented discussions with landholders and with Local Councils. Standard operating procedures in conjunction with site-specific controls will be developed to minimise impact to acceptable levels. Emergency conditions to be considered and mitigated. From a hazard and risk point of view: • Gas wells may be developed in areas where the buffer zone from the wellhead to the boundary of business/open space exceeds 30 m and to a neighbouring business or industrial development exceeds 10 m. • Gathering lines (low or medium pressure) may be established in areas zoned as active open space, business or industry provided the easement is maintained and provided the location, threat and risk analysis provide acceptably risk levels. • FCFs may be developed in areas where the buffer space exceeds 30 m to neighbouring business and active open space. Neighbouring industrial facilities may be established at the site boundary of the FCF. • CGPFs and IPFs may be developed in areas where the buffer space exceeds 80 m to neighbouring business. Neighbouring industrial facilities and active open space may be established at the site boundary of the CGPF or the IPF. • High pressure gas pipelines: The design requirements for *Industrial* (I) or *Heavy Industrial* (HI) will apply for pipelines installed within the measurement length of 864 metres of an industrial development. Special design requirements for pipelines installed within land defined as a Common Infrastructure Corridor (CIC), or which because of its function results in multiple (more than one) infrastructure development within a common easement or reserve, or in easements which are in close proximity.	YES	YES	YES

E4.2 Risks During Design and Installation

Most risks during design and construction are rated as *Low*, with the exception of the following risks, which are rated as *Medium* in accordance with the risk matrix definitions:

- Fire risk due to ignition of flammable or combustible material;
- Injury to workers during construction;
- Ignition of dry grass, brush or vehicle during access on track causing bush fire;
- Threat to people, plant and equipment due to external event such as bush fire;
- Injury to driver due to transportation risks; and
- Safety risk from holes, ditches, uneven terrain, heavy and light vehicle movement.

The wells and the gathering system are likely to be constructed on locations containing numerous safety hazards such as ditches, holes, uneven terrain and sharp objects. The land is also likely to contain venomous snakes and spiders. Installation of these developments will also involve heavy machinery, rotating equipment and handling of electrical sources. Such risks are standard for Arrow Energy and are managed using industry standard practices, internal safety, health and environmental procedures and protocols.

Risks to workers during initial commissioning of wells, gathering system, FCFs, CGPF, IPFs from potential ignition of flammable gas will be assessed and managed prior to introduction of a source of ignition.

E4.3 Risks During Operation and Maintenance

Several of the risks during operation and maintenance are rated as *Medium*. These are outlined below:

- Fire risk due to ignition of flammable or combustible material;
- Operator injury and equipment damage due to pressure burst;
- Exposure due to loss of containment of liquids or pollutant materials;
- Injury to workers during use of heavy machinery or heavy equipment;
- Ignition of dry grass, brush or vehicle during access on track causing bush fire during construction, use and maintenance;
- Threat to people, plant and equipment due to external event such as bush fire;
- Injury to driver due to transportation risks.

Incidents during production and handling of gas have the potential to affect areas outside of the immediate compound or site. The gas can ignite in the presence of oxygen (air) and an ignition source. If ignited, gas can either burn as a fire or explode (in the case of a confined release), generating overpressure effects. Fires pose the hazard of intense heat, open flame and smoke inhalation. Fires may also cause damage to equipment and on-site or off-site facilities.

On-site populations who may be exposed to hazards associated with the production, transport and treatment of the flammable CSG comprise personnel, contractors and visitors. The types of hazards which require consideration for people inspecting, visiting, maintaining and working with these developments during operation, maintenance and workover operations are outlined below:

- Flammable and pressure hazards from the gas;
- Mechanical hazards from rotating machinery and moving vehicles;

- Exposure to harmful materials such as saline water, diesel or oil (and, in the case of the CGPF, to corrosive water treatment chemicals) and;
- Electrocution hazards (power lines, generators and other electrical equipment).

Another risk to which on-site populations would be subject relates to the very large quantities of water contained on the IPF site and the potential for a failure of dam walls and subsequent flooding of the site.

For these risks, Arrow will apply internal Safety Management Systems, including the preparation of contingency and emergency response plans. Dam integrity requirements are heavily controlled through the application of Department of Environment and Resource Management (DERM) dam safety guidelines and dam approval process requires a Dam break assessment as part of the DERM granting approval. Further, the State Planning Policy 1/03, *Mitigating the Adverse Impact of Flood, Bush Fire and Landslide* apply.

Risk imposed from the local environment on on-site populations is predominantly associated with the risk of bush fires. As determined in the Planning Assessment report, which forms part of the EIS, the hazard rating for the Surat Gas Project development area is a mixture of *medium* and *low* hazard with predominantly *low* hazard areas. All of the proposed developments are acceptable in l*ow* to *medium* bush fire hazard areas provided State Planning Policy 1/03, *Mitigating the Adverse Impact of Flood, Bush Fire and Landslide* is implemented. For bush fire risks, Arrow will apply internal Safety Management Systems, including the preparation of contingency plans and will consult with local Rural Fire Services.

By observing standard road transport requirements for hazardous material, as defined in the *Australian Code for the Transport or Dangerous Goods by Road or Rail*, the risk associated with such transportation is very small and is managed through standard procedures by the transport companies.

Issues associated with loss of containment include the potential for loss of containment of polluting materials such as lubricating oil and diesel (at the gas wells, FCFs, CGPFs and IPFs), and tri-ethylene-glycol (TEG) and water treatment chemicals (at the CGPFs and IPFs). The application of standard risk management practices as defined in the relevant Australian Standard (for example AS1940 for combustible liquids and AS3780 for corrosive liquids) will minimise this risk.

Further risk is associated with the potential for loss of containment of saline waters from the gas wells, the gathering lines and the CGPF / IPF. Rigorous risk management practices during the design, installation, operation and maintenance of these facilities will minimise the risk of loss of containment of saline waters.

E4.4 Risks During Decommissioning and Rehabilitation

Risks during decommissioning are very similar to the risks during installation, as discussed under E3.1 above.

These risks include failure to follow adequate purge and blow-down procedures (i.e. failure to safely depressure plant and equipment prior to introducing air into the system) and general safety hazards encountered during construction from uneven ground and the presence of venomous snakes and spiders, and the use of heavy machinery, electrical equipment and rotating equipment.

There are also risks to workers during decommissioning of wells, gathering system, IPFs from potential ignition of flammable gas which need to be assessed and managed prior to introduction of a source of ignition.

Further, as with all construction and decommissioning sites, there will be fuels and lubricating oils stored at the sites which need to be managed using standard risk management practices for combustible liquids, as defined in AS1940-2004.

No significant risks with off-site consequences (such as those associated with fire, explosions or release of hazardous materials) have been identified for the decommissioning and rehabilitation stages for this development. Hazards for personnel and contractors involved with this work would be managed using Arrow Energy safety, health and environmental procedures and protocols.

E5 Recommendations

To ensure an acceptable risk associated with the proposed facilities, which form part of the proposed development, the recommendations below apply:

Recommendation 1: Design pressure of pipe and equipment in gas usage shall be at well above the maximum operating pressure of the plants and equipment, to be defined in Arrow design documentation.

Recommendation 2: Overpressure protection of the gas wells should be provided in order to protect downstream equipment. If and where pressure relief valves are used, these should be designed to vent to a *safe location*, i.e. away from people and potential ignition sources, allowing the gas to safely disperse.

Recommendation 3: It is recommended that at least the emergency isolation valves at the battery limits for the CGPF should be *fire proof*, providing prolonged integrity in case of exposure to a fire (at least 90 minutes).

Recommendation 4: A major incident at a compressor or at the export pipe between the compressors and the battery limit should initiate an automatic Emergency Shut Down and flaring of the contents in the affected plant to safe location (this is relevant for each of the FCFs, CGPFs and the IPFs). Each compressor should be fitted with isolation valves at the inlet and the outlet of the compressor, which should be set to shut in case of a major incident, and the affected compressor to flaring.

Recommendation 5: Hazardous area classification drawings should be prepared for all plants where flammable gas may be present, including where the gas is released after transportation in the water stream. All electrical equipment should be fitted and maintained in accordance with hazardous area codes and requirements.

Recommendation 6: Adherence to Arrow Energy risk management systems and procedures should be strictly checked during construction and operation of all facilities, with particular attention to Permit to Work (PTW) and Control of Management of Change (MOC).

Recommendation 7: Maintenance of all plant and equipment should be performed according to a set protocol and shall include visual inspections through to non-destructive testing techniques. Any flexible lines (e.g. on gas wells) should be included on a preventative maintenance register. A systematic maintenance and testing program should be established for all local and remote control and monitoring systems.

Recommendation 8: Technical personnel should be trained in what constitutes *safety critical equipment,* such as ESD systems and pressure safety valves, and that the removal of any such item must be controlled through the Management of Change (MOC) (or other suitably managed system).

Recommendation 9: It is recommended that a number of the <u>key</u> requirements that are established under AS2885 (pipelines Code for high pressure gas and liquid petroleum pipelines) should be applied also for the gathering pipelines even though this type of low to medium pressure pipes does not strictly need to adhere to this Code. Such key requirements should include (but not be limited to) registration of the gathering pipes with the Dial-Before-You-Dig program (or equivalent system); placement of sign posting along the length of the pipeline; and conducting of *location* and *threat analysis* before deciding on the routing of any part of the gathering system.

Recommendation 10: Atmospheric storage tanks used for potentially polluting or hazardous material should be bunded to appropriate Code requirement (e.g. AS1940 for combustible liquids and AS3780 for corrosive water treatment chemicals). Bunds should be kept closed at all times (except during controlled discharge of clean rain water) – adherence to this requirement should be regularly audited.

Recommendation 11: Minimisation of the risk to people, plant and equipment from bush fires should be achieved through the preparation of emergency response plans, including planning for evacuation and determining the appropriate action to take with respect to either maintaining production or, if safe to do so, to shut down and vent. This may be achieved through the implementation of State Planning Policies and Australian standards in managing bush fire risks.

Recommendation 12: Fire breaks and fuel (timber, grass etc.) management of the area around the wells, the gathering line easement, the FCFs, the CGPFs and the IPFs should be determined in conjunction with Rural Fire Services.

Recommendation 13: The compressor areas should be hard stand gravel (no grass) and the maintenance plan for the sites should include the requirement to remove combustible materials and vegetation from the site.

Recommendation 14: In order to minimise the likelihood of a leak at the gas wells it is recommended that all the above ground pipe lengths are minimised (particularly at the high pressure side of the flow control valve); that hard-pipes are used instead of flexible lines; and that a hierarchical approach is taken to the design of connections welded connections should be used wherever possible, followed by the use of flanged connections where welding is not practicable and where the use of screwed connections is only used as a last resort due to operational or maintenance requirements. These requirements should form part of Arrow's design guidelines.

Recommendation 15: The fence surrounding the gas wells should be constructed such that the Hazardous Zone (as per Area Classification) is contained within the compound.

Recommendation 16: Assess the practicality of including an automatic response to a fire scenario at the gas wells in the form of an automatic isolation of the well. Note that the predominant factor influencing the risk is associated with jet fires – therefore the detection should to be able to pick up the presence of a flame. Methods that should be reviewed include fire detectors or burn-through nylon tubing.

Recommendation 17: Scheduling of internal and external audits to ensure that the safety management systems are functioning properly and that it is appropriate to the hazards associated with the facilities. Detailed specialist audits of engineering and safety issues should be carried out at regular intervals not exceeding every four years with the first audit conducted within six months to one year of commissioning of the first facilities. The detailed specialist audit should be conducted in accordance with recognised audit methodology, such as that described in the Department of Urban Affairs and Planning, Hazardous Industry Planning Advisory Paper No. 5: *Hazard Audit Guidelines*; 1993 Edition

Recommendation 18: Construction and commissioning safety management plans to be developed for each type of facility associated with this project.

Recommendation 19: Fire safety requirements for each type of facility to be established in conjunction with the Rural Fire Brigades and the local Fire Brigades.

Recommendation 20: Emergency plans to be developed for each type of facility. Site-specific details will need to be included.

Recommendation 21: HAZOP (Hazard and Operability) studies to be conducted during the design process of each type of facility forming part of the present development proposal.

Recommendation 22: Trips and alarm philosophy as well as venting, blowdown and relief requirements to be established during the design process.

Recommendation 23: In AS1940, process vessels are not required to be bunded. However, as the glycol is used hot in the CGPF and IPF process it is recommended that bunding is installed to contain the glycol in case of a spill. Bunding design and construction to (at least) conform to AS1940 requirements.

GLOSSARY AND DEFINITIONS

AS	Australian Standard
Arrow Energy	Arrow Energy Pty Ltd
ALARP	As Low As Reasonably Practical
APIA	Australian Pipeline Industry Association
BOP	Blow Out Preventer
CGPF	Central Gas Processing Facility
CIC	Common Infrastructure Corridor
CSG	Coal Seam Gas
DERM	Department of Environment and Resource Management
EIS	Environmental Impact Statement
EGIG	European Gas Incident Group
ESD	Emergency Shut Down
GRE	Glass Reinforced Epoxy
Fraccing	Hydraulic fracturing, a process that results in the creation of fractures in rocks. The fracturing is done from a wellbore drilled into reservoir rock formations to increase the rate and ultimate recovery of oil and natural gas. This is not done for the present development
FCF	Field Compression Facility
HAZMAT	Hazardous Materials
HDPE	High Density Polyethylene
HIPAP	Hazardous Industry Planning Advisory Paper
HSE	Health, Safety and Environment
HSEMS	Health, Safety and Environment Management System
IAOGP	International Association of Oil & Gas Producers
IPF	Integrated Processing Facility
JSEA	Job Safety and Environment Analysis
LFL	Lower Flammable Limit
LNG	Liquefied Natural Gas
MAOP	Maximum Allowable Operating Pressure
MOC	Management of Change
MSDS	Material Safety Data Sheet
NDT	Non Destructive Testing
NZS	New Zealand Standard
OGP	Oil & Gas Producers
PHA	Preliminary Hazard and Risk Assessment
PM	Preventative Maintenance
PPE	Personal Protective Equipment
PV	Pressure Vessel
PSV	Pressure Safety Valve

PTW	Permit To Work
QRA	Quantitative Risk Analysis
SCC	Stress Corrosion Cracking
SGP	Sales Gas Pipeline
SIL	Safety Integrity Level
SOP	Standard Operating Procedures
UFL	Upper Flammable Limit
TEG	Tri-ethylene glycol
TOR	Terms of Reference
US DOT Office	US Department of Transportation Office

REPORT

1 INTRODUCTION

1.1 BACKGROUND

Arrow Energy Pty Ltd (Arrow) is an integrated energy company with interests in coal seam gas field developments, pipeline infrastructure, electricity generation and proposed liquefied natural gas (LNG) projects.

Arrow has interests in more than 65,000 km^2 of petroleum tenures, mostly within Queensland's Surat and Bowen basins. Elsewhere in Queensland, the company has interests in the Clarence-Moreton, Coastal Tertiary, Ipswich, Styx and Nagoorin Graben basins.

Arrow's petroleum tenures are located close to Queensland's three key energy markets; Townsville, Gladstone and Brisbane. The Moranbah Gas Project in the Bowen Basin and the Tipton West, Daandine, Kogan North and Stratheden projects in the Surat Basin near Dalby comprise Arrow's existing coal seam gas production operations. These existing operations currently account for approximately 20% of Queensland's overall domestic gas production.

Arrow supplies gas to the Daandine, Braemar 1 and 2, Townsville and Swanbank E power stations which participate in the National Electricity Market. With Arrow's ownership of Braemar 2 and the commercial arrangements in place for Daandine and Townsville power stations Arrow has access to up to 600 MW of power generation capacity.

Arrow and its equity partner AGL Energy have access rights to the North Queensland Pipeline which supplies gas to Townsville from the Moranbah Gas Project. They also hold the pipeline licence for the proposed Central Queensland Gas Pipeline between Moranbah and Gladstone.

Arrow is currently proposing to develop the Arrow LNG Project, which is made up of the following aspects:

- Arrow LNG Plant – The proposed development of an LNG Plant on Curtis Island near Gladstone, and associated infrastructure, including the gas pipeline crossing of Port Curtis.
- Surat Gas Project – The upstream gas field development in the Surat Basin, subject of this assessment.
- Arrow Surat Pipeline Project – (Formerly the Surat Gladstone Pipeline), the 450 km transmission pipeline connects Arrow's Surat Basin coal seam gas developments to Gladstone.
- Bowen Gas Project – The upstream gas field development in the Bowen Basin.
- Arrow Bowen Pipeline – The transmission pipeline which connects Arrow's Bowen Basin coal seam gas developments to Gladstone.

Arrow proposes expansion of its coal seam gas operations in the Surat Basin through the Surat Gas Project. The need for the project arises from the growing demand for gas in the domestic market and global demand and the associated expansion of LNG export markets.

The project development area covers approximately 8,600 km^2 and is located approximately 160 km west of Brisbane in Queensland's Surat Basin. The project development area extends from the township of Wandoan in the north towards Goondiwindi in the south, in an arc adjacent to Dalby. Townships within or in close proximity to the project development area include (but are not limited to) Wandoan, Chinchilla, Kogan, Dalby, Cecil Plains, Millmerran, Miles and

Goondiwindi. Project infrastructure including coal seam gas production wells and production facilities (including both water treatment and power generation facilities where applicable) will be located throughout the project development area but not in towns. Facilities supporting the petroleum development activities such as depots, stores and offices may be located in or adjacent to towns.

The conceptual Surat Gas Project design presented in the environmental impact statement (EIS) is premised upon peak gas production from Arrow's Surat Basin gas fields of approximately 1,050 TJ/d. The peak gas production comprises 970 TJ/d for LNG production (including a 10% fuel gas requirement for facility operation) and a further 80 TJ/d for supply to the domestic gas market.

A project life of 35 years has been adopted for EIS purposes. Ramp-up to peak production is estimated to take between 4 and 5 years, and is planned to commence in 2014. Following ramp-up, gas production will be sustained at approximately 1,050 TJ/d for at least 20 years, after which production is expected to decline.

Infrastructure for the project is expected to comprise:

- Approximately 7,500 production wells drilled over the life of the project at a rate of approximately 400 wells drilled per year.
- Low pressure gas gathering lines to transport gas from the production wells to production facilities.
- Medium pressure gas pipelines to transport gas between field compression facilities and central gas processing and integrated processing facilities.
- High pressure gas pipelines to transport gas from central gas processing and integrated processing facilities to the sales gas pipeline.
- Water gathering lines (located in a common trench with the gas gathering lines) to transport coal seam water from production wells to transfer, treatment and storage facilities.
- Approximately 18 production facilities across the project development area expected to comprise of 6 of each of the following:
  - Field compression facilities.
  - Central gas processing facilities.
  - Integrated processing facilities.
- A combination of gas powered electricity generation equipment that will be co-located with production facilities and/or electricity transmission infrastructure that may draw electricity from the grid (via third party substations).

Further detail regarding the function of each type of production facility is detailed below.

Field compression facilities will receive gas from production wells and are expected to provide 30 to 60 TJ/d of first stage gas compression. Compressed gas will be transported from field compression facilities in medium pressure gas pipelines to multi-stage compressors at central gas processing facilities and integrated processing facilities where the gas will be further compressed to transmission gas pipeline operating pressure and dehydrated to transmission gas pipeline quality. Coal seam water will bypass field compression facilities.

Central gas processing facilities will receive gas both directly from production wells and field compression facilities. Central gas processing facilities are expected to provide between 30 and 150 TJ/d of gas compression and dehydration. Coal seam water will bypass central gas processing facilities and be pumped to an integrated processing facility for treatment.

Integrated processing facilities will receive gas from production wells and field compression facilities. Integrated processing facilities are expected to provide between 30 and 150 TJ/d of gas compression and dehydration. Coal seam water received at integrated processing facilities is expected to be predominantly treated using reverse osmosis and then balanced to ensure that it is suitable for the intended beneficial use. Coal seam water received from the field, treated water and brine concentrate will be stored in dams adjacent to integrated processing facilities.

It is envisaged that development of the Surat Gas Project will occur in five development regions: Wandoan, Chinchilla, Dalby, Kogan/Millmerran and Goondiwindi. Development of these regions will be staged to optimise production over the life of the project.

Arrow has established a framework to guide the selection of sites for production wells and production facilities and routes for gathering lines and pipelines. The framework will also be used to select sites for associated infrastructure such as access roads and construction camps. Environmental and social constraints to development that have been identified through the EIS process coupled with the application of appropriate environmental management controls will ensure that protection of environmental values (resources) is considered in project planning. This approach will maximise the opportunity to select appropriate site locations that minimise potential environmental and social impacts.

Arrow has identified 18 areas that are nominated for potential facility development to facilitate environmental impact assessment (and modelling). These are based on circles of approximately 12 km radius that signify areas where development of production facilities could potentially occur.

Arrow intends to pursue opportunities in the selection of equipment (including reserve osmosis units, gas powered engines, electrical generators and compressors) and the design of facilities that facilitates the cost effective and efficient scaling of facilities to meet field conditions. This flexibility will enable Arrow to better match infrastructure to coal seam gas production. It will also enable Arrow to investigate the merits of using template design principles for facility development, which may in turn generate further efficiencies as the gas reserves are better understood, design is finalised, or as field development progresses.

An overview of the function of each type of compression and processing facility is provided in Section 1.2.1 and detailed in Section 2 below.

As part of the project approval process by the Queensland Government and the Commonwealth Government, an EIS is being prepared to assess potential impact on the environment from the proposed development and ensure that appropriate measures are in place to avoid or minimise the identified impacts.

This PHA was prepared as part of the EIS to determine the risk to people and property from potential significant incidents associated with the proposed development. The PHA follows the requirements in the Final Terms of Reference (TOR, Ref 1) for this development.

1.2 Scope and Aim of Study

Planager Pty Ltd has been commissioned to conduct this PHA in order to assess the risk to people and property associated with the Arrow Energy Pty Ltd Surat Gas Project.

As per the requirements of the final Terms of Reference (TOR) (Ref 1), the PHA describes the potential hazards and risk to people and property from significant potential incidents that may be associated with the proposal (as distinct from risk of impact to the natural environment, which is addressed in other sections of the EIS).

This PHA addresses the following two requirements specified in the TOR:

1. Detail the values related to people and property that could be affected by any hazardous materials and actions associated with the proposal; and
2. Assessment of the potential hazards that may be associated with the proposal, their potential impacts, mitigation measures and risks.

It is too early to state definitively “when” and “where” project activities will occur over the entire project life. Hence, a risk-based framework approach has been used in this PHA, using knowledge of existing activities and early concept development, to identify and assess impacts and risks. The framework approach will be used to inform ultimate project development and avoid and reduce potential impacts and risks down to generally tolerable risk levels.

1.2.1 Facilities Included in the Hazard and Risk Assessment

The Coal Seam Gas (CSG) is extracted from the well, piped through the gathering system, and processed (i.e. compressed and dehydrated) in the Central Gas Processing Facility (CGPF). The CGPF may or may not form part of the overall Integrated Processing Facility (IPF) where the water - also extracted from the well and piped through the gathering system in a separate pipe - is treated in a water treatment plant. If required, the gas passes through a Field Compression Facility (FCF) on it’s way to the CGPF and/or the IPF in order to boost the pressure.

The scope of this PHA includes the risk associated with the gas wells through to the FCFs, CGPFs and the IPFs and onwards into the high pressure pipelines up to the point where they connect up with the Arrow Surat Pipeline.

The risks associated with the transport to the gas network using the Arrow Surat Pipeline has been assessed previously (Ref 2) and does not form part of the present PHA.

Hence, this report assesses the risks associated with the following facilities:

- Gas wells (including downhole equipment and well head facilities with separator vessel, pumps, electric drives and generators, electrical and control panel, instrumentation, piping and valving to control the flow of the gas and coal seam water from the well to the gathering system;
- Gathering lines (low pressure buried gas and water pipelines of a high-density polyethylene (HDPE) and medium pressure buried gas pipelines of lightweight, plastic composite, glass reinforced epoxy (GRE) or steel used to deliver gas from the well heads to the field compression facilities and onwards to the CGPF or IPF;
- Field Compression Facilities (FCFs) – (to boost the gas pressure within the gathering lines towards the treatment facilities, including a small number of compressors);
- Central Gas Processing Facilities (CGPFs) (high-pressure compression facilities (including power supply) where gas is dehydrated to sales specification and increased to export pipeline pressure; and a water transfer station including pumps and associated pipe work for the pumping of water between facilities); and
- Integrated Processing Facilities (IPFs) (high-pressure compression facilities (including power supply) where gas is dehydrated to sales specification and increased to export pipeline pressure and water treatment facilities for the treatment, storage and disposal of coal seam water);
- High pressure gas pipelines between CGPFs and/or IPFs to the Arrow Surat Pipeline, designed to transport gas from the outlet of CGPFs and IPFs to the main Arrow Surat Pipeline, Surat Header Pipeline or Daandine Hub.

- Water treatment facilities (located at the IPF and including water treatment plant (filtration and reverse osmosis plant).
- Storage dams, holding dams, brine dams and associated pumps and pipe work).
- Power supply (as required for plant, equipment and facilities; a combination of grid-provided power, via overhead lines and local electricity power generation (using gas drives) as appropriate.

Other facilities included in the operation of the above facilities are workshops, warehouses, offices and other operating infrastructure as well as depots to accommodate administration, engineering and production, supervisory support, occupational health and safety management, stores, well workover functions and the associated personnel.

The Arrow Surat Pipeline and the Surat Header Pipeline (an extension of the Arrow Surat Pipeline) are not within the scope of this hazard and risk assessment.

1.2.2 Operations Included in the Hazard and Risk Assessment

The risk associated with the above facilities is assessed from their construction and onwards, as follows:

- Design and installation (including drilling and casing of wells, digging and trenching pipelines, constructing plant and equipment, and bringing the equipment into production);
- Normal operation and maintenance; and
- Decommissioning and rehabilitation.

1.2.3 Types of Risks Reviewed

The types of risks considered in this PHA are:

- Risk of human injury or fatality;
- Risk of propagation of an incident to neighbouring facilities or damage to property.

The gas processed and handled is mainly composed of methane with some traces of nitrogen and carbon dioxide. It is flammable, a simple asphyxiant[1] and has no toxic properties. As CSG is lighter than air it will rise quickly above the ground in case of release to air. Combustion products of CSG are water, carbon dioxide (and possibly carbon monoxide under very adverse conditions such as combustion in an enclosed area with insufficient air-ingress).

The coal seam gas will be described as *gas* in this report.

There is no acute health risk potential from the burning of gas in air (the combustion products are carbon dioxide and water) and hence this aspect is not covered in the PHA. Further, this PHA does not include an analysis of scheduled releases, such as gas flaring, or minor fugitive emission type releases. Such releases are discussed elsewhere in the EIS and are usually regulated by Environmental Licence conditions.

Risks to workers associated with manual handling operations and with the movement of heavy machinery, equipment or heavy vehicles are assessed and managed through Permit To Work

[1] Methane is classified as an asphyxiant in the guidelines on National Exposure Standards (NES) for atmospheric contaminants in the occupational environment (Australian Safety and Compensation Council 2009). Asphyxiants are gases that when present in an atmosphere in high concentrations, lead to a reduction of oxygen.

and Job Safety and Environment Analysis (JSEA) processes and other tools, rather than via the PHA process.

1.3 STATEMENT OF ENVIRONMENTAL VALUES

1.3.1 Discussion

The Surat Basin covers an area of approximately 300,000 km^2 between south-eastern Queensland and northern New South Wales. The basin forms part of the larger Great Australian Basin covering west across the Nebine Ridge with the Eromanga Basin and east across the Kumbarilla Ridge with the Clarence-Moreton Basin.

The petroleum exploration and production tenements held by Arrow in the Surat Basin are concentrated along the Condamine River Valley, extending in an arc from Wandoan in the northwest towards the Dalby Area to the southeast, and then beyond Cecil Plains and Millmerran in the south.

The map in Figure 1 shows the extent of the Surat Gas Project development area.

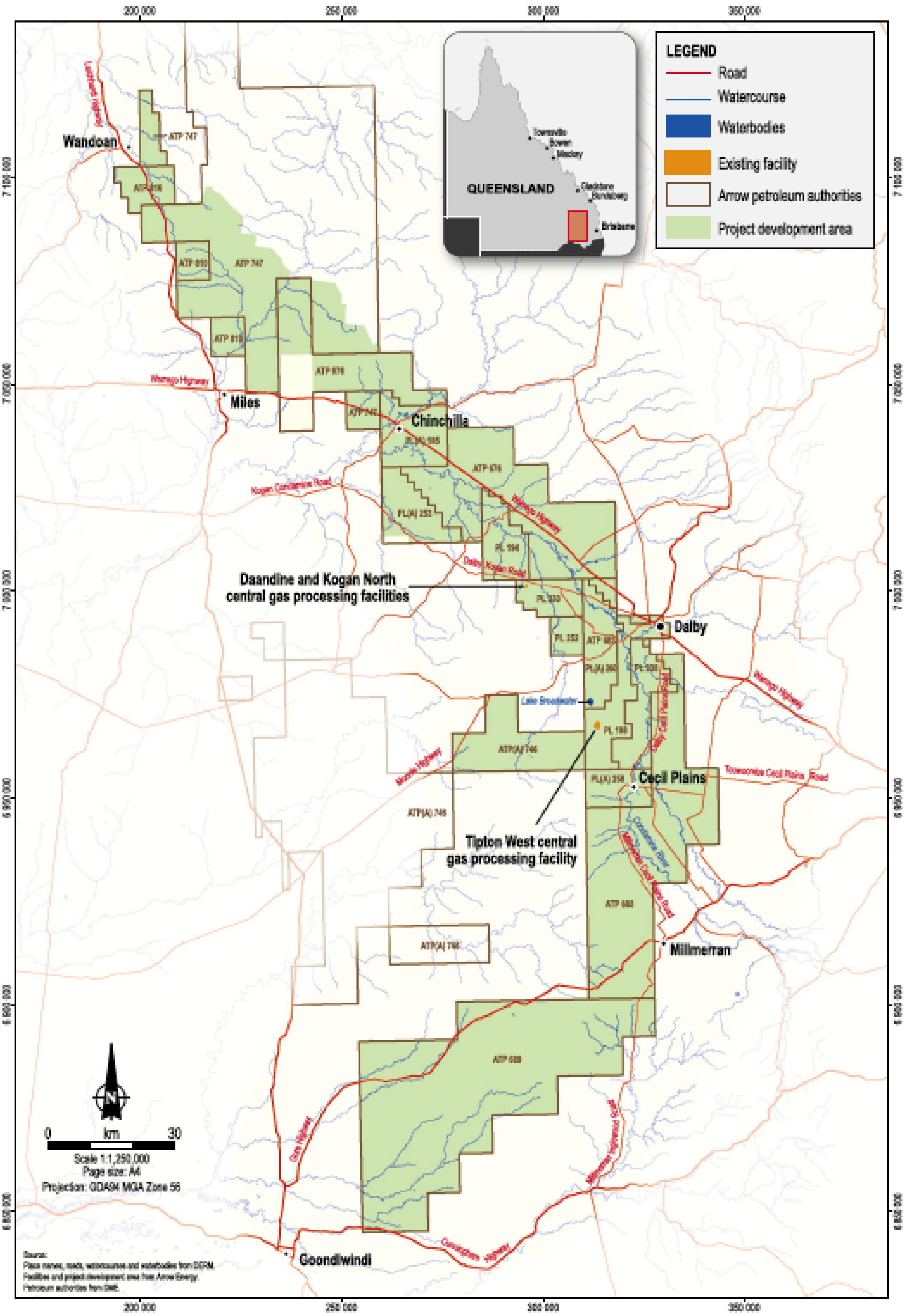
The Surat Gas Project development area is composed predominantly of rural areas used for sheep, cattle grazing and cultivation. There are also vast areas of bushland and state forests.

Population is generally dispersed, except for towns and townships, which include Dalby, Chinchilla, Cecil Plains and Wandoan.

With this dispersed population it is possible to develop the Surat Gas Project development area for petroleum exploration and operation whilst ensuring safety of people living and working in the area and minimising the risk of damage to residences or local business from adverse effects of this development. This would be achieved by avoiding town and townships and by maintaining adequate buffer zones between the petroleum activities and the local population.

The extent of these buffer zones around the activities which form part of this development, from a hazard and risk point of view, are determined as part of this PHA and the results are presented in Section 7.

Figure 1 - Surat Basin Area Proposed for Development



1.3.2 Legal Framework

To enable this type of development, the facilities which form part of the project would need to adhere to Australian and/or internationally recognised laws, regulations, standards, codes and guidelines. The following listing provides a listing of some of the major legal framework documents that come into play for the proposed development. Further details are provided in Appendix 1. Please note that this is not an exhaustive listing.

Risk Assessment Guidelines

- ISO31000 - *Risk management* (Ref 3)
- In the absence of guidelines published in Queensland, the following NSW guidelines are commonly referred to in QLD and in the rest of Australia (these guidelines follow generally accepted international methods for Quantitative Risk Analysis):
  - Hazardous Industry Planning Advisory Papers number 6 - Guidelines for Hazard Analysis (Ref 4);
  - Hazardous Industry Planning Advisory Papers number 4 - *Risk Criteria for Land Use Planning* (Ref 5);
  - *Locational Guidelines - Development in Vicinity of Operating Coal Seam Methane Wells* (Ref 6);
- AS/NZ2885.1, *Pipelines – Gas and Liquid Petroleum*, Part 1 (Ref 7)

Laws and Regulations

- Petroleum and Gas (Production and Safety) Act 2004 (Qld) (Ref 8)
- Petroleum and Gas (Production and Safety) Reg's 2004 (Qld) (Ref 9)
- Environmental Protection Act 1994 (Qld) (Ref 10)
- Petroleum and Other Legislation Amendments Act 2004, 2005 (Qld) (Ref 11)
- Workplace Health and Safety Act 1995 (Qld) (Ref 12)
- National Occupational Health and Safety Standard NOHSC: 1007 1993 (Commonwealth) (Ref 13)
- Electrical Safety Act 2002 (Qld) (Ref 14)

1.4 METHODOLOGY

1.4.1 Overview

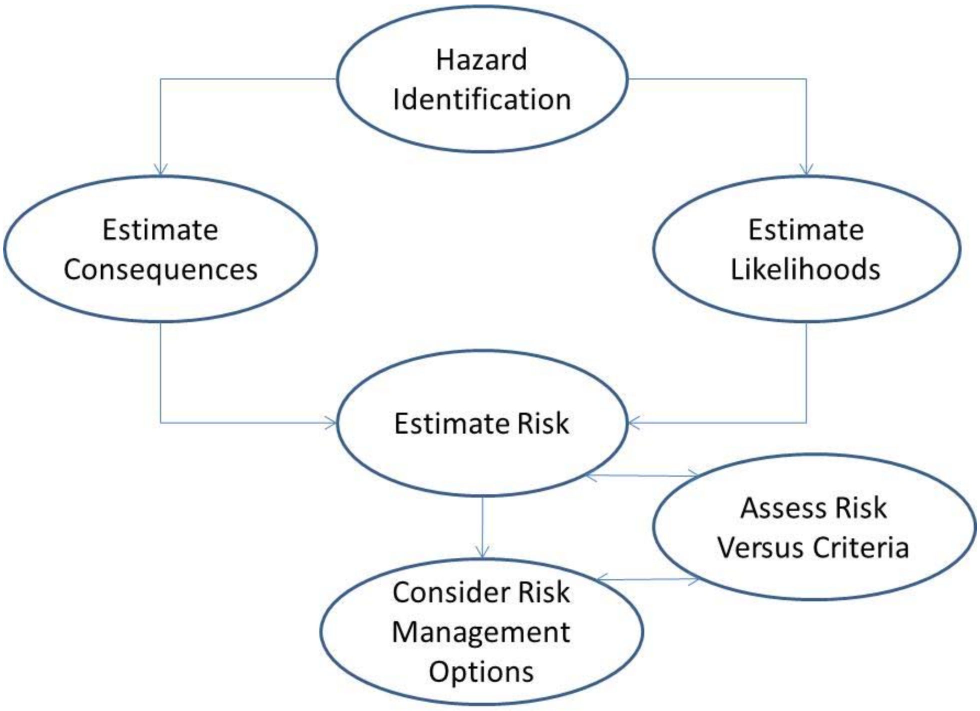
The methodology for the risk assessments is well established in Australia. The PHA has been carried as per the ISO 31000:2009 - *Risk management - Principles and guidelines* (Ref 3).

The assessment of risk to the people and property, including to the public around the facilities forming part of the proposed development involves the application of the basic steps outlined below. The methodology used attempts to take account of all possible significant hazardous situations that may arise.

Risk has been estimated both qualitatively (in Sections 3, 4 and 5) and quantitatively in Section 6.

A general outline of the risk assessment process is conceptually depicted in Figure 2 below.

Figure 2 – General Risk Analysis Process



The risk for each incident is evaluated according to:

Risk = Consequence x Frequency

The risks associated with a hazardous event are commonly defined as a function of the following four elements:

- The likelihood of the event — such as a loss of containment event;
- The consequences associated with the event — such as thermal radiation from a fire due to release;
- The effects of the event — such as the thermal damage or level of injury from a fire, and;
- The effectiveness of systems for preventing the event or mitigating hazards and consequences — such as safety and security systems.

As per standard risk assessment methodologies, the risk analysis process involves a systematic consideration of the possible initiation, development and consequences of potential hazards, as well as any mitigating factors.

This preliminary assessment covers standard operating conditions and assumes that standard industry control measures are in place.

1.4.2 Hazard Identification

The hazard identification process has been based on the following reviews:

- Assessment of the hazardous properties inherent to gas recovery, processing and handling.

- Completion of a systematic *Conceptual Hazard and Operability Study (Conceptual HAZOP Study)* by a multidisciplinary team from design, operations, safety, environment and maintenance[2] functions for the proposed development (Arrow Energy report Ref 15).
- Review of previous hazard identification studies, such as a number of in-house Arrow studies and reviews (Arrow reports Refs 16, 17, 18, 19, 20 and 21).
- Review of historical incidents and near misses which have occurred at similar facilities;
- Assessment of location specific issues and threats;
- Definition of the relevant hazardous incident scenarios.

The purpose of the hazard identification step was to identify significant hazards and ensure that there are appropriate measures to eliminate or reduce the risk to tolerable levels. Potentially hazardous events were identified together with the causes and consequences.

A presentation of hazards from all sources is provided in Section 3.

1.4.3 Quantitative Risk Assessment

A. Consequence Calculations

Consequence calculations were carried out on each of the significant incidents determined. Calculations were performed using well established and recognised correlations between outflow rates, consequences if the gas is ignited and the effect on people and property if they are exposed to a flammable event. Consequence analysis was undertaken using the Netherlands Organisation for Applied Scientific Research – TNO's - consequence modelling software program *Effects* (version 8.0) and TNOs risk assessment program Riskcurves (v 7.6). The detailed calculations are presented in Appendix 3.

The TNO tools are internationally recognised by industry and government authorities. The models used within Effects and Riskcurves are well known and are fully documented in the TNO "coloured books", including the Yellow Book (Ref 22). For information on the modelling software used, refer to Appendix 3.

The main types of incidents, which are of concern for the proposed development, are those involving a flammable event relating to the release and subsequent ignition of the gas.

In order for these events to occur, there are two requirements, namely loss of containment and ignition. Causes of gas releases are equipment failure and deficient operations. Initiating release scenarios include:

- Leaks during routine operation from fixed piping, fittings, valves, or process vessels due to equipment failure or mechanical damage; and
- Leaks during drilling, equipment installation, maintenance or workover operations;
- Leaks due to third party interference, e.g. digging and trenching from farm machinery or road works, impact incidents, vandalism and sabotage.

The composition of CSG is predominantly methane gas (about 97 to 98%), with some nitrogen and carbon dioxide. The gas may include very small quantities of ethane, propane and butane (less than 0.05%).

[2] Note that this PHA was conducted at the preliminary design stage and does not include a detailed process analysis (e.g. HAZOP or Fault Tree analysis). This type of analysis would normally be completed by a multidisciplinary team including plant designers, construction and process engineers, safety specialist and operations management as the final stages of detailed engineering design of the plant and pipeline.

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 CSG) are listed in the table below:

Table 1 – Properties of Methane Gas

Property	CSG (approx. 95 – 97% methane)
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°C

Discussion as to the behaviour and properties of CSG is provided in Section 1.4.2 above. The results of a release of the gas depend on the properties and behaviour of the gas upon release into the atmosphere. The following credible outcomes could be expected, depending on the circumstances of the release:

- Jet fires, resulting from the ignition of a (semi-) continuous release of CSG producing a long, stable, high temperature flame[3];
- Flash fires, occurring when a cloud of CSG vapour is ignited, resulting in a flame travelling through the cloud; and
- Vapour Cloud Explosion, occurring when a large cloud of CSG vapour is ignited. Vapour Cloud Explosions associated with lighter than air gases (such as CSG) generally require confinement for the cloud to accumulate.

The gathering lines and the high pressure gas pipelines are installed in the open air with no confinement. In such case, the risk of vapour cloud explosions is unlikely. In the case of the wells, this is consistent with the approach taken in the NSW Department of Planning *Locational Guidelines* (Ref 6).

In the more confined areas of the FCF, the CGPF and the IPF, vapour cloud explosion has been included in the assessment as it is possible though improbable.

The effect of a flammable event on people depends on the duration of exposure and their distance away from the fire. Flash fires are, by their nature, extremely powerful over very short time durations. Jet fires are less powerful but their effect may last over a much longer time period.

The gas is non-toxic, posing only an asphyxiation hazard. Due to its buoyancy, any release of credible proportions from operations of this scale, in the open, are highly unlikely to present an asphyxiation hazard for off-site population. With standard confined space entry procedures and appropriate security arrangements to prevent unauthorised access to any of the facilities the risk associated with asphyxiation from CSG should be minimal.

The impact potential from hazards associated with CSG is listed in the table below:

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[3] Please note that, in case of a low-pressure, low velocity release, the resulting fire may be much shorter and less stable the in the case of the jet fire and generally would not result in equipment damage or injury.

Table 2 – Impact Potential for Coal Seam Gas

Hazard	Threat Zone	
	Level of Concern	**Level or Method of Estimation**
Thermal radiation from Jet Fire	Fatality	The probability of fatality from exposure to a jet fire is based on a probit calculation, which incorporates the heat radiation at the target (kW/m^2) with the duration of exposure to the jet fire (in minutes).
Thermal radiation from Flash Fire	Fatality	The probability of fatality from exposure to a flash fire is based on 100% of people within a flame envelope. The flame envelope is equal to the Lower Flammable Limit contour
Overpressure effects from vapour cloud explosion	Fatality	The probability of fatality from exposure to overpressure waves in excess of 30kPa is taken as 100%. Overpressures of less than 30kPa are not considered potentially lethal.
Downwind toxic effects of fire by-products from combustion of released gas	Combustion products are mainly carbon dioxide and water – not toxic. Thermal lift from heat of fire – very low concentrations at ground level. No thresholds - Not modelled by *TNO Effects.*	
Asphyxiation exposure to CSG	Local effects only – possible hazard to on-site populations. Managed through Permit to Work and JSEA processes. No thresholds - Not modelled by *TNO Effects.*	
Frostbite from exposure to CSG	Local effects only – possible hazard to on-site populations. Managed through Permit to Work and JSEA processes. No thresholds - Not modelled by *TNO Effects*.	

The consequence distances of some incident scenarios extend beyond the gas well compound and the IPF site boundary. However, due to the robust risk management designed into the facilities, once the likelihood of occurrence of major incidents has been taken into account, they may not contribute significantly to the cumulative individual risk of fatality at that location.

B. Likelihood Estimations

Frequency estimations involve consideration of historical accident and equipment failure rate data from a number of recognised sources. Four factors are considered when determining the likelihood of the consequences resulting from the identified failure cases:

- The basic failure rate of each type of failure (for example the likelihood of a particular hole size per metre of piping);
- The overall failure rate applicable to the case, taking into account the piping lengths and equipment configurations;
- The probability of ignition of the released flammable gas, i.e. that a jet fire or a flash fire will occur; and
- The probability of a certain effect, e.g. injury, fatality or equipment damage.

The failure rate data and the ignition probabilities for the gas wells used in this study are discussed in Section 6 and in Appendix 4.

C. Risk Evaluation

No formal risk assessment guidelines or risk criteria have been published in Queensland as yet. The guidelines developed by the NSW Department of Planning in their *Hazardous Industry Planning Advisory Paper* (HIPAP) No 6 – *Guidelines for Risk* Analysis (Ref 4) and HIPAP No 4 - *Risk Criteria for Land Use Planning* (Ref 5) follow internationally recognised practices for hazard and risk assessments and are commonly adopted for these types of assessments in Queensland and elsewhere in Australia and have therefore been adopted for the present PHA.

In May 2004, the NSW Department of Planning further prepared a set of guidelines for coal seam methane (CSM) gas wells, entitled *Locational Guidelines - Development in Vicinity of Operating Coal Seam Methane Wells* (Ref 6). The aim of these guidelines was to provide advice for consent authorities across NSW in assessing proposals for the development in the vicinity of existing and future operating wells. While prepared for NSW, these guidelines have been referred to in the present PHA and adapted for the local Surat Gas Project conditions and for the Arrow well design.

In order to assess the risk profile of the proposed development, it is necessary to calculate the risk at a number of locations so that the overall impact can be assessed.

In the quantitative risk assessment, the event frequency and hazard consequence data has been combined to produce estimates of risk using Riskcurves, TNO's risk calculation and contour plotting program. Risk levels are calculated by considering each modelled scenario, and combining its frequency with the extent of its *harm footprints*.

Riskcurves considers all scenarios, for each wind-weather combination, and sums their risk contributions across all points. It is then used to plot *iso-risk contours* (i.e. lines of constant risk) to represent *individual risk*. Note that individual risk calculations conservatively assumes that a person is present at a given location, outdoors, all of the time (24 hours per day, 365 days per year), and takes no account of the individual occupancy of the area or the chance that people could escape or seek shelter indoors. In practice the actual risks to persons in these areas would be much lower, since people would only be present outdoors for a fraction of the time.

The results of the risk analysis are presented in the following forms:

- *Individual Fatality Risk*, i.e. the likelihood (or frequency) of fatality to notional individuals at locations around the site, as a result of any of the postulated incidents. The units for individual risk are probability (of fatality) per million per year.
- *Injury and Propagation Risk*, i.e. the likelihood of injury or propagation to individuals or plant at locations around the site as a result of the same scenarios used to calculate individual fatality risk (above). The units for injury and irritation risk are probability (of injury/propagation) per million per year.

The calculated risk results can then be compared with the relevant risk criteria (Ref 5) as summarised below.

Individual risk at a given location is generally expressed as the peak individual risk, defined as the risk of fatality to the most exposed individual located at the position for 24-hours of the day and 365 days in the year. Since residential areas tend to be occupied by at least one individual all the time, the above definition would easily apply to residential areas. A person indoors would receive natural protection from fire radiation and hence the risk to a person indoors is likely to be lower than to one in open air. In this study, the individual risk levels have been calculated for a person in open air.

For land uses other than residential areas (that is, industrial, open space or commercial) where occupancy is not 100% of the time, individual risk is still calculated on the same basis. However, the criteria for acceptability are adjusted for occupancy.

Table 3 – Risk Criteria

Land Use	**Suggested Criteria (x 10^{-6} per year)**
Sensitive development (hospitals, schools, child-care facilities, old age housing)	0.5
Residential (and hotels, motels, tourist resorts)	1
Business (commercial developments including retail centres, offices and entertainment areas)	5
Active open space (including sporting complexes)	10
Boundary of an industrial site (facility generating risk) (max risk at boundary of the site which generates the risk)	50
Injury risk criteria (4.7kW/m^2, 7kPa)	50
Propagation risk criteria (23kW/m^2, 14kPa)	50

In order to put these risks into perspective, published information on the level of risk that each of us may be exposed from day to day due to a variety of activities has been shown in Table 4 below. Some of these risks are *voluntary*, for which we may accept a higher level of risk due to a perceived benefit, while some are *involuntary*. Generally, we tend to expect a lower level of *imposed* or *involuntary* risk especially if we do not perceive a direct benefit. The criteria have been chosen so as not to impose a risk which is significant when compared to the background risk the average person is already exposed to.

Table 4 – Risk to Individuals

Activity / Type of Risk	**Published levels of risk (x 10^{-6} per year)**
VOLUNTARY RISKS (AVERAGED OVER ACTIVE PARTICIPANTS)	
Smoking	5,000
Drinking alcohol	380
Swimming	50
Playing rugby	30
Travelling by car	145
Travelling by train	30
Travelling by aeroplane	10
INVOLUNTARY RISKS (AVERAGED OVER WHOLE POPULATION)	
Cancer	1,800
Accidents at home	110
Struck by motor vehicle	35
Fires	10
Electrocution (non industrial)	3
Falling objects	3
Storms and floods	0.2
Lightning strikes	0.1

1.4.4 Qualitative Assessment

Not all risks can be evaluated quantitatively and hence, for completeness, a qualitative approach to risk assessment has also been carried out for all incidents identified with potentially detrimental effects to people and property. The risks have been classified in accordance with the risk matrix, as presented in Appendix 4. This is a 5 x 5 risk matrix, which is compatible with the risk matrix in the Code for gas and liquid petroleum pipelines, AS2885 (Ref 7).

1.4.5 Meteorological Data

The meteorology of the site plays a role in determining the location and the degree of offsite impacts of activities carried out at the site. The meteorological data, incorporated into the risk assessment, is provided in Appendix 3.

1.5 OCCUPATIONAL HEALTH AND SAFETY MANAGEMENT SYSTEMS

1.5.1 Legal Situation

Operators of an operating plant are obligated under The Petroleum and Gas (Production and Safety) Act 2004 (Ref 8) to prepare safety management plan(s) (SMPs) to the extent that they are appropriate to the plant. The SafeOp document (Ref 23), prepared by the QLD Department of Natural Resources and Mines, provides guidance to operators on the matters they must include in a safety management plan (SMP) to ensure that it complies with the Petroleum and Gas (Production and Safety) Act and Regulation.

With respect to the present development the Petroleum and Gas (Production and Safety) Act and Regulation the following activities and facilities are covered:

- Exploration and production industry;
- Drilling and well servicing plant;
- Pipelines (licensed transmission pipelines under the Act)
- Petroleum processing plant (not refineries other than those on petroleum authorities)
- Natural gas distribution networks (distribution authorities)
- Power generation (gas fired plant that uses more than 50 GJ/hr) at any time.

1.5.2 Arrow Energy’s Approach

The Arrow Health, Safety and Environment Management System (HSEMS) Manual is prepared to meet these requirements. Arrow has deployed a set of key performance indicators to proactively manage Health and Safety performance across all its operations by aiming to achieve zero injuries. The Arrow HSEMS exceeds the OHS best practice requirements as detailed in Australian Standard (AS/NZS) 4801 for Safety Management (Ref 24) and International Standard OHSAS 18001 (Ref [25]). The HSEMS involves 11 main activities bound by a commitment to continuous improvement. It is prepared to support the Target Zero commitment to zero injuries and includes the following management systems:

Leadership & Commitment: Introduction from the Chief Executive on his commitment of Occupational Health and Safety, followed by the OHSM Policy and the Target Zero overview and explanation.

Risk Management: Arrow commits to identification and management of risk as a continual process, which must be considered and managed in all elements of their OHSM System. Business units are required to determine the processes and procedures for hazard identification and risk management; to establish for hazard and risk identification systems, including risk management training and awareness to employees and contractors; to prepare. Hazard Register(s) to document and describe the hazards (to personnel, facilities, the public customers and the Company reputation); and to ensure that effective controls are utilised to ensure the risks are reduced to *As Low As Reasonably Practicable* (ALARP) levels.

Change Management: All temporary and permanent changes to the organisation, personnel, systems, procedures, equipment, products, materials or substances used in Arrow are evaluated and appropriate action taken to ensure levels of risk remain at ALARP levels.

People: Arrow's OHSM System requires personnel to be carefully selected, appropriately trained and competent to enable them to perform work in a safe manner. Further, personnel need to be provided with details of their roles and responsibilities and how their individual efforts contribute towards improving OHS performance ensures everyone plays a part in minimising potential losses.

Incident & Emergency Management: Arrow's incident and emergency management requirements include the need to document emergencies; OHS and security incidents; production losses; loss of asset integrity; and ethics violations or conflicts of interest. It is recognised that some incidents can escalate into an emergency situation. Plans, equipment, training and other resources will therefore need to be identified, documented and maintained for all foreseeable emergency and crisis situations. Incidents must be reported and investigated to prevent recurrence by identifying and managing immediate and root causes.

Asset Management: Arrow guidelines require that all new and existing facilities will be designed, procured, constructed, commissioned, operated and maintained such that the integrity of the facility is assured and risks to the health and safety of people are effectively controlled.

Information Management: Arrow recognises that effective and efficient information management provides a competitive advantage to a company. Arrow commit to the use of contemporary information management infrastructure and supporting processes and systems which ensure OHS documents, data and records are comprehensive, captured, shared, revised and stored.

Customers, Contractors & Suppliers: Arrow's customers, contractors and suppliers performance is key to implementation and achievement of the zero incident and zero injury safety target. Arrow are committed to providing a healthy and safe workplace for all employees, consultants, contractors, service providers and visitors across all facets of our operations.

Communication & Consultation: Arrow commits to an environment of trust, openness and involvement through proactive, transparent and effective communication and consultation processes with its employees, contractors, regulatory agencies, clients, partners, public organisations, surrounding businesses, communities and other stakeholders.

Performance Monitoring, Measurement & Reporting: Arrow monitors, measures and reports on OHS performance through means such as surveys, inspections and sampling. Results are analysed and reported against OHS standards, objectives and targets.

Systems Review: At determined intervals, or as a result of change or significant event, Arrow commits to seeking assurance that the OHSM System is working effectively. Assurance is achieved through a process of assessing and measuring compliance with the expectations of the Arrow OHSMS. Opportunities for improvement of the OHSMS will be identified and implemented as part of Arrow's commitment to continual improvement.

1.5.3 Safety Management System Integration into Quantitative Risk Assessment

In quantitative risk assessments, incidents are assessed in terms of consequences and frequencies, leading to a measure of risk. Where possible, frequency data used in the analysis comes from actual experience, e.g. near misses or actual incidents. However, in many cases, the frequencies used are generic, based on historical information from a variety of plants and processes with different standards and designs.

As with any sample of a population, the quality of the management systems (referred to here as "safety software") in place in these historical plants will vary. Some will have little or no software, such as work permits, planned maintenance and modification procedures, in place. Others will have exemplary systems covering all issues of safe operation. Clearly, the generic frequencies derived from a wide sample represent the failure rates of an "average plant". This hypothetical average plant would have average hardware and software safety systems in place.

If an installation which has significantly below average safety software in place is assessed using the generic frequencies, it is likely that the risk will be underestimated. Conversely, if a plant is significantly above average, the risk will probably be overestimated. However, it is extremely difficult to quantify the effect of software on plant safety. Incorporating safety software as a means of mitigation has the potential to significantly reduce the frequency of incidents and also their consequences if rigorously developed and applied. The risk could also be underestimated if safety software is factored into the risk assessment but is not properly implemented in practice. Practical issues also arise when attempting to factor safety software into the risk assessment – applying a factor to the overall risk results could easily be misleading as in practice it may be the failure of one aspect of the safety software that causes the accident, while all other aspects are managed exemplarily.

In this study it is assumed that the generic failure frequencies used apply to installations which have safety software corresponding to accepted industry practice and that this site has similar management practices and systems. This assumption it is believed, will be conservative in that it will overstate the risk from well managed installations.

2 FACILITIES AND OPERATION

The terms that are applicable to the Surat Gas Project field development are defined as follows:

- *Wells* are the basic unit of field development and comprise one cased bore hole and associated surface and subsurface equipment.
- Well *pods* comprise a small number of wells (approximately 10) that are geographically collocated and linked by common infrastructure such as gathering pipelines and access tracks.
- Well *parcels* comprise approximately 100 wells or approximately 10 pods. The term parcels is a reservoir engineering term that also represents a portion of a larger resource tenure.
- Well *fields* or gas fields comprise a number of parcels (or parts thereof), which contain all of the wells that supply a particular facility such as a field compression facility, central gas processing facility or integrated processing facility.
- *Development regions* comprise a number of fields (approximately three or four) and all of the wells and facilities located in those fields. Arrow's operations will predominantly be managed and supported at a regional level.
- The *project development area* comprises the area containing all of Arrow's proposed development under the Surat Gas Project as defined above.

The project development area is divided into five broad development regions which are used for purposes of field development planning: Dalby, Wandoan, Millmerran/Kogan, Chinchilla and Goondiwindi. Arrow expects to locate facilities at approximately 25 km intervals throughout the project development area to gather gas and water from production wells.

The development area has been divided into parcels that each contains about 100 production wells (the estimated maximum number of wells in each parcel being 118 wells).

There will be approximately:

- 7,500 production wells and associated gas and water gathering infrastructure;
- six field compression facilities (FCFs);
- six central gas processing facilities (CGPF) and
- six integrated processing facilities (IPFs).
- The FCFs will contain one or multiple first stage compression trains depending on the quantity of gas being delivered from wells in the area.
- The CGPFs will incorporate water transfer facilities.
- The IPFs will incorporate CGPFs and water treatment and storage facilities and power generation (as required).

Compression, power generation and water treatment equipment will be *modular*, allowing facilities to be scaled up and down to cope appropriately with gas and water abstraction volumes and through the different stages of the development's life. In this sense the term modular means that components for facilities will be constructed on site, using the same types of equipment, in the same layout, facility after facility. Produced water will bypass FCFs.

The gathering system is a network of low to medium pressure pipelines, which connect each of the gas production wells with the CGPFs or IPFs. It will run underground from the gas wells up to the CGPFs or IPFs and is located in consultation with landowners and local authorities. The length of the gathering lines will depend but is generally less than 20km between wells and CGPFs. Along the way there may be a need for a FCF to boost the pressure in the pipeline allowing for the transportation of the gas to the CGPF.

Where possible, CGPF, power generation, water treatment and water storage facilities, will be co-located in one IPF. Due to co-location, the IPF sites will require an area of approximately 750m by 350m. Further, approximately 100 hectares of dams to store associated water (feed water, treated water, oily water and brine concentrate) will be required at each IPF.

Power required to run the compressors will be generated on-site (through a local power generation facility of 20 to 48 MW) or from network connection involving extension of the existing electricity distribution network.

In the case of on-site power generation, reciprocating gas engine generators may be used, generating at high efficiency (40% to 47% efficiency or higher) with engine emission control, which may be sized at 2 or 3 MW each.

Information relating to design and operation of the gas wells, gathering system and CGPF, as used in this PHA, is shown in the following tables. Further details are provided in Appendix 1.

Table 5 – Equipment and Facilities Configuration

Component	Function	Material of construction	Wall thickness [mm]	Diameter (internal) [mm]	Length [m]	Pressure [kPa(g)] – maximum operating	Limiting Factors to the Flow in Case of a Leak
Gas Well	Casing and tubing	Steel	Not determined as yet (prelim. design)	Casing liner: 200 Tubing: 73	150-750	- 175 (free flowing) - 4200 (shut-in, max)	For full bore rupture: infinite. For ≤ 10% hole size: infinite.
Gas Well	**Gas:** Well head collar up to remote operated isolation valve.	Steel with short flexible coupling.	Not determined as yet (prelim. design)	80	2.5-5	- 175 (free flowing) - 4200 (shut-in, max).	For full bore rupture: infinite. For ≤ 10% hole size: infinite.
Gas Well	**Water:** Well head collar up to remote operated isolation valve.	Steel with short flexible coupling.	Not determined as yet (prelim. design)	50	2.5-5	- approximately 350 - 650 (shut down pressure to suit Gathering system MAOP)	For full bore rupture: infinite. For ≤ 10% hole size: infinite.
Gas Well	Remote operated isolation valve (gas) to gathering line tie-in point.	Steel with short flexible coupling.	Not determined as yet (prelim. design)	80	5-8	- 110-120 (normal operating). - 300 (max, PSV opens).	For full bore rupture: infinite. For ≤ 10% hole size: infinite.
Gathering line – gas	Gathering line tie-in point at well up to inlet compressor at FCF, CGPF or IPF.	HDPE (for the low pressure lines) or GRE or steel (for the medium pressure lines)	Not determined as yet (prelim. design)	From 100 (at well) and up to 630 (at the FCF, CGPF, IPF)	Up to 20 km	At well: - 100 (low pressure). - 1000 (medium pressure).	Infinite until isolation of remote control valve. Infinite if remote control valve fails.
Field compression facility	Compressor train	Steel	Not determined as yet (prelim. design)	50	500	1000	Full bore and >10% hole: Limited by amount of gas between emergency isolation valves. Infinite if remote ctrl valve fails. For <10% hole, limited by compressor capacity.

Component	Function	Material of construction	Wall thickness [mm]	Diameter (internal) [mm]	Length [m]	Pressure [kPa(g)] – maximum operating	Limiting Factors to the Flow in Case of a Leak
Central gas processing facility and Integrated gas processing facility	Compressor train	Steel	Not determined as yet (prelim. design)	50	500	9800	Full bore and >10% hole: Limited by amount of gas between emergency isolation valves. Infinite if remote ctrl valve fails. For <10% hole, limited by compressor capacity.

Indicative compression facility capacities and water treatment requirements for the FCFs are presented in Table 6 and Table 7 below.

Table 6 - Gas Handling and Processing in Field Compression Facilities

Typical equipment	Typical flow range (TJ/d)	Number of compressors	Discharge MAOP (kPa)	Gas treatment
Gas powered engines, electric motors, compressors, cooling fans, separators, control and safety systems, electrical panels, pipework and SCADA.	30 – 60	Screw compressors: 3 to 6 and Reciprocating compressors: 1 to 2	1,000	No

Table 7 - Water Handling and Processing in Field Compression Facilities

Typical equipment	Equipment Associated with Water Handling	Water Treatment / Disposal Activities	Throughput Volume Requirement (ML/d)	Nominal storage volumes
Inlet slug catcher; separation facility; and facility for collection of water condensed during compression.	None	Collection and disposal of entrained water and water condensed during compression process	No coal seam water treatment onsite. 100% bypass to CGPF or IPF.	Approx. 1ML

Indicative compression facility capacities and water treatment requirements for the CGPFs are presented in Table 8 and Table 9 below.

Table 8 - Gas Handling and Processing in Central Gas Processing Facilities

Typical equipment	Typical flow range (TJ/d)	Number of compressors	Discharge MAOP (kPa)	Gas treatment
Gas powered engines, electric motors, compressors (including dehydration), cooling fans, separators, control and safety systems, electrical panels, pipework, SCADA and control rooms and ancillary systems.	30 - 150	Screw compressors: 3 to 15 and Reciprocating compressors: 1 to 6	10,200	Yes

Table 9 - Water Handling and Processing in Central Gas Processing Facilities

Typical equipment	Equipment Associated with Water Handling	Water Treatment / Disposal Activities	Throughput Volume Requirement (ML/d)	Nominal storage volumes
Inlet slug catcher; separation facility; and facility for collection of water condensed during compression.	None	Collection and disposal of entrained water and water condensed during compression and dehydration process	None	<10ML (Oily Water Dam)
Transfer dam; water transfer station (field or field compression facility to integrated processing facility)	Electric variable-speed drive pump (assume 100 kW electric)	Pumping of coal seam water collected from gathering network to an integrated processing facility	No coal seam water treatment on site. 100% transfer to integrated processing facility	600 ML

Indicative gas compression facility capacities and water treatment requirements in the IPFs are presented in Table 10 and Table 11 below.

Table 10 - Gas Handling and Processing in Integrated Processing Facilities

Typical equipment	Typical flow range (TJ/d)	Number of compressors	Discharge MAOP (kPa)	Gas treatment
Gas powered engines, electric motors, compressors (including dehydration), cooling fans, separators, control and safety systems, electrical panels, pipework, SCADA and control rooms and ancillary systems.	30 - 150	Screw compressors: 3 to 15 or Reciprocating compressors: 1 to 10	10,200	Yes

Table 11 - Water Handling and Processing in Integrated Processing Facilities

Typical Equipment	Equipment Associated with Water Handling	Water Treatment / Disposal Activities	Throughput Volume Requirement (ML/d)	Nominal storage volumes
Inlet slug catcher; separation facility; and facility for collection of water condensed during compression.	None	Collection and disposal of entrained water and water condensed during compression and dehydration process	None	<10ML (Oily Water Dam or combined with Utility dam for water treatment facility)
Water treatment facilities and holding dams for brine, treated water and feedstock including: • Feedwater dam. • Reverse osmosis plant. • Treated water dosing capability. • Brine dam. • Treated water dam. • Treated water transfer pumping station (to beneficial use).	• 45 kW, motors for supplying power for the transfer of water between local dams. • 45 kW, motors for power for transferring water to beneficial use pipelines.	Pumping of coal seam water collected from gathering network to an integrated processing facility.	Up to 100% of produced coal seam water through modular reverse osmosis plant (30 to 60 ML/d).	840 ML feedwater; 960 ML treated; 2 x 1440 ML brine.

3 QUALITATIVE RISK ASSESSMENT, DESIGN AND INSTALLATION

A qualitative risk assessment, using the risk matrix provided in Appendix 4, was conducted for the design and installation (including commissioning) phase for the facilities, which form part of the present hazard and risk assessment. The qualitative risk assessment presented in Sections 3.6 to 3.6 below.

The qualitative risk assessment presented below considered the *cumulative* risk for the wells and pipelines. Whether the risk of one well or one stretch of pipeline is acceptable becomes less pertinent when several thousands of wells and several hundreds of kilometres of pipeline are being installed. The risk for each individual facility would hence be much lower than what is stated in the present report. However, the FCFs, CGPFs and IPFs were evaluated as stand-alone facilities.

3.1 COAL SEAM GAS WELLS

3.1.1.1 Hazardous Materials

The inventory, for each class of substances listed in the Australian Dangerous Goods Codes, to be held on-site during design and construction of gas wells is listed below:

Table 12 – Potentially Hazardous Chemicals Used During Design and Construction of Wells

Hazardous Materials Product Name (Correct Shipping Name)	HazChem / UN Number	Forecasted Project Quantity	Colour Rating as Provided By Arrow Energy
Petrol (Petrol)	3YE / 1203	160 litres	Amber
Alclean 5032 (Corrosive Liquids N.O.S. (Phosphoric Acid))	2X / 1760	200 kg	Amber
Superglue (Environmentally hazardous substance, Liquid N.O.S Bisphenola-epichlorohydrin epoxy resin	3YE / (no UN number available)	32 litres	Amber
Squirts (Aerosol) Range (Aerosols)	2YE / 1950	<10kg	Amber
Pine-o-Clean Glen 20 Surface Spray Disinfectant Aerosol (Aerosols)	2Y / 1950	<3kg	Amber
Mortein Lure and Kill High Performance Surface Spray Aerosol (Aerosols)	2Y / 1950	<3kg	Amber
Various solvents and thinners	2YE or 3YE / various	<100 litres / kg	Amber

Specifications, for the safe handling and storage of these materials, include bunding and ventilation arrangements, control of ignition sources, and requirements for personal protective equipment.

Arrow has an occupational health and safety management system Provided that the internal (Arrow) and external (Dangerous Goods) requirements are followed the risks associated with these materials is considered to be minor.

3.1.2 Potentially Hazardous Incidents

The main hazardous incident scenarios relating to the design and installation of the gas wells are listed below:

- Fire risk due to ignition of flammable or combustible material;

- Fire incident involving gas released during blowdown which catches fire and causes injury or destruction of property;
- Personnel injury due to pressure burst (i.e. from a non-ignited releases which may cause injury to a person standing nearby, typically a maintenance worker);
- Injury to workers during rigging up / down, during well head completions, and during well tests;
- Ignition of dry grass / brush during vehicle access on access track bush fire during construction, use and maintenance;
- Threat to people, plant and equipment due to external event such as bush fire;
- Injury to driver during transportation and operation/interaction of heavy vehicle movements (lifting etc.)
- Injury due to loss of containment of liquid hazardous materials (diesel, hydraulic oil, bentonite, drilling foam) or saline water;
- Injury due to electrocution at faulty electrical equipment or from power surges;
- Confined space hazards to operators and contractors;
- Flammable gas co-mingles with water source.

The potential hazardous consequences and associated mitigating strategy of the above scenarios are listed in the table below.

The risks (after application of controls) have been ranked in accordance with the risk matrix (presented in Appendix 4). Only the safety risks are included.

The risk is rated as the combined risk for all gas wells at all locations. The risk per well would be much lower, probably by at least one (or two) levels.

Risk to Arrow property does not form part of the present PHA as this will be covered under Arrow's internal procedures.

Table 13 – Hazard Identification Word Diagram, Gas Wells Design and Installation

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Fire or explosion risk	Ignition of flammable or combustible material, including incident involving gas released during blowdown catches fire and causes injury or destruction of property.	**Prevention:** Standard Operating Procedures (SOPs) will be developed for this project. Well Control and Blow Out Prevention (BOP) procedures will be established, as well as site training and induction programs (only trained and experienced contractors will be used). HSE Audits and inspections, designated smoking areas, Hazardous Zones defined and enforced. Blow-out of pipes to clean from construction debris will be done using well established procedures and under strict controls, including those detailed in risk assessments. **Protection:** Extinguisher servicing/inspection, Emergency response plan and fire drills.	Moderate	Likely	Medium Risk
Operator injury and equipment damage due to pressure burst.	Failure of formation pressure control and well control; blowout (swabbing, low fluid viscosity); extreme down hole losses, damage to wellhead equipment; free gas in wellbore due to blockage in existing well or laterals - potential gas pocket; circulation piping failure including during pressure testing; well becomes alive during operation (failure of barriers); over pressure system (e.g. blockage) resulting in sudden release of pressure.	**Prevention:** Offset well data available; drilling program; all key personnel maintain current well control certification; rig crew are competency based trained and drilled in these scenarios; all equipment certified and procedure in place; stabbing valve and other relevant equipment; personnel trained to detect kicks by signs of the well flowing or the presence of gas bubbles in the well fluid; BOP Test procedures are in place for the Drilling Contractor; pressure testing procedure used by drilling contractor; SOPs. **Protection:** Strength of equipment design. Emergency Response Procedure.	Minor	Possible	Low Risk

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Injury to workers during construction activity, including during rigging up / down, during well head completions, and during well tests.	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.	**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, SOPs and approved scaffolding procedures, certified personnel and lifting equipment, lifting ops, PTW (*Life saving rules* for working at heights and suspended loads), JSEA's 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. Rig move plan and load out plan. BOP installed at all times during flow testing, down hole tools are managed under the contractor's procedures, pressure testing and inspection of lines, whip check or safety chain, tie downs or equivalent on all high pressure lines, front-end loader operators to be licensed - use crane when available, tag lines to be used on all suspended loads, inspection / register of harnesses and height safety equipment and anchor points, process to clear area during perforating activities, housekeeping. **Protection:** Machinery guarding, appropriate PPE worn, personal fall arrest equipment, Wrist straps and lanyards to secure tools to be used at heights. Emergency procedures/drills, first aid trained personnel on site.	Moderate	Unlikely	Medium Risk

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Ignition of dry grass/brush during vehicle access on track causes bush fire during construction, use and maintenance.	Construction and use of the access track would cause vegetation and ground cover clearance and potential for erosion, dust being generated and weed spreading. Access by vehicles on the access track could cause brush and bush fire.	**Prevention:** Track selection to avoid sensitive environmental areas. Track maintenance in accordance with SOP. Speed limits (minimises dust generation and deterioration). Vehicle weed control. Use of designated track only. Fire prevention SOP. **Protection:** Fire extinguisher in vehicle.	Moderate	Possible	Medium Risk
Threat to people, plant and equipment due to external event such as bush fire.	External event such as a bushfire impacting on the people working at the site causing injury. Possible impact on above ground facilities such as vents could cause damage to equipment leading to release of flammable gas which would burn.	**Prevention:** Fire breaks and fuel (timber, grass, etc.) management around above ground facilities and power poles. Above ground facilities and vents are metallic which provides some resistance to a fire. Control of activities during extreme fire danger periods. **Detection:** Visual inspection of power lines and above ground facilities after bushfire. **Protection:** SOPs and emergency procedures.	Moderate	Possible	Medium Risk

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Injury to driver due to transportation risks and working in isolation	Driver inexperience, fatigue, excessive speed for conditions, mechanical failure, environmental conditions (dust, rain, sunlight), wildlife / livestock on roads, road surface condition e.g. rocks, potholes, loose gravel, road works and associated machinery, traffic management, cement and construction trucks, school bus hours - causes accident and injury.	**Prevention:** Driver training, travel management plans, Audits /Inspections of procedures and equipment by health, safety and environment advisors, drive to road conditions, PM program, driver assessment in Safe Vehicle SOPs for Remote Locations, clearly defined Transport Management policy and procedures, supervision by Drillers and Rig Managers, designated drivers for Drill Rig Contractor vehicles, detailed route planning including nominated rest stops, rig hands couriered to site, drilling contractors training records are audited, Heat Stress management procedures, State Law and 1 of the 12 lifesaving rules. Policy and procedures for working in isolation / lone worker.	Major	Possible	High Risk
Injury due to loss of containment of liquid hazardous materials (diesel, hydraulic oil, bentonite, drilling foam) or saline water.	Loss of containment from storage or during handling of chemicals, e.g. during unloading or transfer causes injury to personnel or contractors from exposure if spill is not appropriately contained and cleaned up.	**Prevention:** Safe operating procedures developed for occupations that work with hazardous substances, training of personnel (personnel responsible for unloading chemicals are certified to operate equipment, pre-job meetings, all Drilling Contractor crews are trained in chemical handling), audits and inspections, suitable storage facilities available following Code requirements, MSDS available, covered in the HSE Induction, legislative requirement for DG Transportation, dedicated cargo handling and storage area, that is cleared of all personnel, signs, HSE Advisers regularly audit this area. **Protection:** PPE, spill kits, Emergency Response Plan and local HAZMAT response plan in the event of a spill.	Minor	Unlikely	Low Risk
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:** Trained and qualified personnel, planned maintenance of electrical equipment, correct grounding of rig electrical circuit, and HSE Audit.	Moderate	Rare	Low

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Confined Space hazards to operators and contractors	Asphyxiation and dermal absorption hazards in case of access to pits and vessels.	**Prevention:** Signposting, PTW system, HSE Audits and Advice, appropriate equipment provided, specialised training, (JSEA) for all confined space entry jobs, confined space entry training, contained within the 12 lifesaving rules.	Moderate	Rare	Low
Flammable gas co-mingles with water source	Possible flammable gas in water source. Ignition potential leading to injury or destruction of property	**Prevention:** Wells will be constructed to avoid mixing between strata. Drilled well travels through commonly used water resource but the well shaft will be sealed (concrete) where well intersects with water resource. Further, the steel piping is of a robust construction, further separating the gas from the water resource. The absence of fraccing in the Surat Gas Project development area development means that geological structures are unlikely to be affected (though they will be intersected). Landowner Bore assessments are required, with Licensed Water Bores in the Walloons Coal Measures identified. Site based risk assessments to further minimise the likelihood.	Major	Rare	Medium Risk

3.2 GATHERING SYSTEM

3.2.1 Hazardous Materials

No chemicals or other dangerous goods will be required for the design and installation of the gathering system.

3.2.2 Potentially Hazardous Incidents

The hazardous incident scenarios relating to the design and installation of the gathering system are listed below:

- Ignition of dry grasses or brush during vehicle access on track causes bush fire during construction which could threaten people in the area.
- Threat to people, plant and equipment due to external event such as bush fire initiated from external sources.
- Injury due to electrocution.
- Confined space risks.
- General safety risks (slip, trip and fall, working under heavy load).

The potential hazardous consequences and associated mitigating strategy of the above scenarios are listed in Table 14 below. The risks (after application of controls) have been ranked in accordance with the risk matrix (presented in Appendix 4).

The risk is rated as the combined risk for all gathering lines at all locations. The risk per gathering line measurement length would be much lower, probably by at least one (or two) levels.

Table 14 – Hazard Identification Word Diagram, Design and Installation - Gathering System

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Access track causes environmental impact or bush fire during construction, use and maintenance.	Construction and use of the access track would cause vegetation and ground cover clearance and potential for erosion, dust being generated and weed spreading. Access by vehicles on the access track could cause brush and bush fire.	**Prevention:** Track selection to avoid sensitive environmental areas. Track maintenance in accordance with SOP. Speed limits (minimises dust generation and deterioration). Vehicle weed control. Use of designated track only. Fire prevention SOP. **Protection:** Fire extinguisher in vehicle.	Moderate	Possible	Medium Risk

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Threat to people, plant and pipelines due to external event such as bush fire or working in isolation.	External event such as a bushfire impacting on the people working at the site causing injury. Possible impact on above ground facilities such as vents could cause damage to equipment leading to release of flammable gas, which would burn.	**Prevention:** Documented in Construction Management Plan. Pipelines are buried to a minimum depth of 750mm - insulation afforded by soil cover precludes damage from bushfire heat radiation, even for non-flowing pipeline. Above ground facilities and vents are metallic which provides some resistance to a fire. Equipment will be designed to withstand considerable heat load, e.g., through use of heat-resistant (fire-safe) isolation valves on production facilities. Control of activities during extreme fire danger periods through development of protocols for the control of operational activities during extreme fire danger periods, e.g., flaring or shutdowns. Driver training, travel management plans, Audits /Inspections of procedures and equipment by health, safety and environment advisors, drive to road conditions, PM program, driver assessment in Safe Vehicle SOPs for Remote Locations, clearly defined Transport Management policy and procedures, supervision by Drillers and Rig Managers, designated drivers for Drill Rig Contractor vehicles, detailed route planning including nominated rest stops, rig hands couriered to site, drilling contractors training records are audited, Heat Stress management procedures, State Law and 1 of the 12 lifesaving rules. Policy and procedures for working in isolation / lone worker. **Detection:** Visual inspection of power lines and above ground facilities after bushfire. **Protection:** SOPs and emergency procedures.	Major	Unlikely	Medium risk

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
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:** Trained and qualified personnel, planned maintenance of electrical equipment, correct grounding of rig electrical circuit, and HSE Audit.	Moderate	Rare	Low Risk
Safety risk from holes, ditches, uneven terrain, heavy vehicles.	Operator injury	Documented in Construction Management Plan. Barricading of trenches and ditches. General safety precautions such as PPE, high visibility vests worn, speed limits, training and procedures apply.	Minor	Likely	Medium Risk
Confined space hazards to operators and contractors	Asphyxiation and dermal absorption hazards in case of access to deep trenches. Risk of earth collapse. Injury risk from impact with heavy machinery.	PTW system, HSE Audits and Advice, appropriate equipment provided, specialised training, (JSEA) for all confined space entry jobs, confined space entry training, contained within the 12 lifesaving rules.	Moderate	Rare	Low Risk

3.3 FIELD COMPRESSION FACILITY

3.3.1 Hazardous Materials

The inventory, for each class of substances listed in the Australian Dangerous Goods Codes, to be held on-site during design and construction of FCFs is listed below:

Table 15 – Potentially Hazardous Chemicals Used During Design and Construction of FCF

Hazardous Materials Product Name (Shipping Name)	HazChem / UN Number	Forecasted Project Quantity	Colour Rating as Provided By Arrow Energy
Battery Terminal Protector (Aerosols)	2Y / 1950	13.5 litres	Amber

Specifications for the safe handling and storage of these types of dangerous goods include bunding and ventilation arrangements, control of ignition sources, and requirements for personal protective equipment.

Arrow has an occupational health and safety management system, which includes policy and procedures for the management of these types of hazards, including the need to establish internal audit and monitoring protocols. Provided that the internal (Arrow) and external (Dangerous Goods) requirements are followed the risks associated with these materials is very low.

3.3.2 Potentially Hazardous Incidents

The hazardous incident scenarios relating to the design and installation of the FCFs are associated with the following potential incident scenarios:

- Fire risk due to ignition of flammable or combustible material.
- Fire incident involving inappropriate use of site flare or gas released during blowdown which catches fire.
- Operator injury and equipment damage due to pressure burst.
- Injury due to loss of containment of liquid hazardous materials (lube oil, diesel).
- Injury due to electrocution at faulty electrical equipment.

The potential hazardous consequences and associated mitigating strategy of the above scenarios are listed in Table 19 below. The risks (after application of controls) have been ranked in accordance with the risk matrix (presented in Appendix 4).

Planager
Risk Management Consulting

Table 16 – Hazard Identification Word Diagram, Design and Installation - Field Compression Facilities

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Fire or explosion risk due to ignition of flammable or combustible material	Ignition of flammable or combustible material causes injury or destruction of property.	**Prevention:** Smoke and/or fire alarms fitted, Procedures will be established, including blow-out and purging requirements and hot work permits, site training and induction, HSE Audits and inspections, designated smoking areas, Hazardous Zones defined and enforced. Blow-out of pipes to clean from construction debris will be done using well established procedures and under strict controls, including those detailed in risk assessments. **Protection:** Extinguisher servicing/inspection, Emergency response plan and fire drills. Fire detection and shutdown (once commissioned)	Moderate	Unlikely	Medium Risk
Fire due to inappropriate use of site flare or inappropriate blow down	Ignition of gas released during blowdown or during inappropriate use of site flare catches fire and causes injury or destruction of property.	**Prevention:** SOPs including blow down and purging requirements. Design of flare to take worst case scenario. **Protection:** Extinguisher servicing/inspection, Emergency response plan and fire drills.	Moderate	Rare	Low Risk
Operator injury and equipment damage due to pressure burst.	Failure of commissioning procedures causes pressure burst and injury to personnel.	**Prevention:** Commissioning personnel are competency based trained and experienced; all equipment certified and procedure in place; pressure testing procedure; SOPs. **Protection:** Strength of equipment design. Emergency Response Procedure.	Moderate	Rare	Low Risk

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Injury due to loss of containment of liquid pollutant materials.	Loss of containment from storage or during handling of pollutant material (e.g. diesel, lube oil) if spill is not appropriately contained and cleaned up.	**Prevention:** Procedures developed for occupations that work with hazardous /pollutant substances, training of personnel (personnel responsible for unloading materials are certified to operate equipment, pre-job meetings, audits and inspections, suitable storage facilities available following Code requirements, MSDS available, covered in the HSE Induction, legislative requirement for DG Transportation, dedicated chemicals handling and storage area, HSE Advisers regularly audit this area. **Protection:** PPE, spill kits, Emergency Response Plan and local HAZMAT response plan in the event of a spill.	Moderate	Rare	Low Risk
Injury to workers during construction of plant	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.	**Prevention:** Documented in Construction Management Plan, training and supervision including induction, training, supervision pre job safety meetings, and manual handling and hand safety training completed by all crews, SOPs and approved scaffolding procedures, certified personnel and lifting equipment, lifting ops, PTW, JSEA's to be conducted prior to all potentially hazardous or non-routine operations, visits/audits by health, safety and environment advisors, Pre Start inspection to be completed, process to clear area during perforating activities, housekeeping. Life saving rules for working at heights and suspended loads. **Protection:** Machinery guarding, appropriate PPE worn, personal fall arrest equipment, Wrist straps and lanyards to secure tools to be used at heights. Emergency procedures/drills, first aid trained personnel on site.	Moderate	Unlikely	Medium Risk

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
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 only allowed to work on site, trained and qualified personnel, planned maintenance of electrical equipment, correct grounding of electrical circuit, and HSE Advisor regular inspections.	Moderate	Rare	Low Risk
Threat to people, plant and equipment due to external event such as bush fire.	External event such as a bushfire impacting on the people working at the site causing injury. Possible impact on above ground facilities such as vents could cause damage to equipment leading to release of flammable gas which would burn.	**Prevention:** Fire break through use of vegetation management around above ground facilities. Above ground facilities are metallic which provides some resistance to a fire. Control of activities during extreme fire danger periods. **Detection:** Visual inspection after bushfire. **Protection:** SOPs and emergency procedures.	Moderate	Unlikely	Medium Risk

3.4 Central Gas Processing Facility

3.4.1 Hazardous Materials

The inventory, for each class of substances listed in the Australian Dangerous Goods Codes, to be held on-site during design and construction of CGPFs is listed below:

Table 17 – Major Storages of Non-Dangerous Goods for Use During Design and Construction of CGPF

Hazardous Materials Product Name	HazChem	Forecasted Project Quantity	Colour Rating as Provided By Arrow Energy
Battery Terminal Protector (Aerosols)	2Y / 1950	13.5 litres	Amber
Triethylene glycol	N/A	10,800 litres	Amber

3.4.2 Potentially Hazardous Incidents

The hazardous incident scenarios relating to the design and installation of the CGPFs are associated with the following potential incident scenarios:

- Fire risk due to ignition of flammable or combustible material.
- Fire incident involving inappropriate use of site flare or gas released during blowdown, which catches fire.
- Operator injury and equipment damage due to pressure burst.
- Injury due to loss of containment of liquid hazardous materials (lube oil, diesel).
- Injury due to electrocution at faulty electrical equipment.

These scenarios have been detailed in Section 3.3 (for FCFs) above and are not repeated here.

Please note that the scenario fire risk scenario due to ignition of flammable or combustible material listed in Section 3.3 refers also to potential ignition of TEG which is a combustible liquid held at high temperatures.

The risk ranking, in accordance with the risk matrix, remains unaltered. No further incident scenarios associated with the design and installation of the CGPFs have been identified.

3.5 Integrated Processing Facilities

3.5.1 Hazardous Materials

The potentially hazardous chemicals at the IPFs are identical to those in use at the CGPFs, as detailed in Section 3.3.1 (for FCFs) above.

3.5.2 Potentially Hazardous Incidents

The hazardous incident scenarios relating to the design and installation of the IPFs are associated with the following potential incident scenarios:

- Fire risk due to ignition of flammable or combustible material.
- Fire incident involving inappropriate use of site flare or gas released during blowdown, which catches fire.
- Operator injury and equipment damage due to pressure burst.
- Injury due to loss of containment of liquid hazardous materials (lube oil, diesel, chemicals).

- Injury due to electrocution at faulty electrical equipment.

These scenarios have been details in Section 3.3 above and are not repeated here. The risk ranking, in accordance with the risk matrix, remains unaltered. No further incident scenarios associated with the design and installation of the IPFs have been identified.

3.6 HIGH PRESSURE GAS PIPELINES

Hazards associated with the transmission pipes are identical to those identified for the high pressure Arrow Energy Surat Pipeline, as reported in the Environmental Impact Statement for this pipeline (Ref 2).

Safety during construction of all high pressure gas pipelines will follow the intent of the Australian Pipeline Industry Association (APIA) for Construction Health and Safety Guidelines (Ref 26), including the preparation of a Construction Health and Safety Plan (*Construction H&S Plan*). This plan will include an identification of hazards and risks associated with the pipeline construction activity.

The scope of the Construction H&S Plan will include mobilisation, construction/installation, fabrication, testing, pre-commissioning and commissioning. It will provide Arrow Energy and contractors with enough detail on the expected health and safety standards for the Project.

The main elements will be as follows:

- Facility/Project Description, including information on location and pipeline, regulatory framework and company requirements in terms of occupational health and safety.
- Formal Safety Assessment, including the basis for procedures to ensure that threats to the pipeline and loss of pipeline integrity are reduced to As Low As Reasonably Practical; and
- Safety Management System, detailing the safety management system required by personnel and contractors involved in this phase of the project.

The Formal Safety Assessment will be conducted in accordance with the methodology for such studies, including the *Safety Management Study* methodology as defined in the high pressure pipelines Code AS2885 (Ref 7) for loss of containment events and other hazard identification and risk assessment processes for construction work environment and activities other than those involving loss of pipeline integrity, using the ISO31000 (Ref 3) approach.

A Risk Control Action Plan will be prepared as part of the Safety Assessment process, where specific actions arising for individual hazards are assigned to responsible persons and for action within specified time frames.

A system to monitor the effectiveness of controls and implementation of the Risk Control Action Plan to continuously improve health and safety performance on the project will be implemented.

For each location where the high pressure gas pipeline will be installed, a risk assessment study will be conducted in accordance with the requirements in the Australian high pressure pipelines code AS2885 (Ref 7). The study will identify the many variations and types of locations through which the pipelines will pass, and the types of threats to and from the pipelines. Moreover, the study will ensure that all possible threats at each location are identified, evaluated and appropriately planned for and managed during pipeline construction and operation.

The risk assessment process consists of the following tasks:

- Location analysis - An identification of the land use and activities that could take place adjacent to the pipeline route;
- Threats analysis - An identification of all possible threats that may impact the pipeline, including location-specific, non-location-specific and general threats. Location specific threats can be external interference activities, such as deep furrow ploughing or excavation of adjacent services. Non-location specific threats are for example road crossing at locations along the route w here third party activity is more likely to impact on the buried pipeline. General threats can be internal / external corrosion, pressures in excess of design pressure or natural disasters (earthquakes, cyclones); and
- Determination of design mitigation - An identification of the mitigation measures that are required to reduce the risk of the identified threats to as low as is reasonably practicable (ALARP). AS 2885 stipulates the minimum number of mitigation measures that should be in place for external interference protection as required for different location classes. There are also design requirements for corrosion, electrical protection and natural events.

For threats that have been identified as credible, a qualitative risk evaluation will be performed, using the risk matrix detailed in AS 2885.1 (Ref 7).

4 QUALITATIVE RISK ASSESSMENT, OPERATION AND MAINTENANCE

A qualitative risk assessment, using the risk matrix provided in Appendix 4, was conducted for the operation and maintenance (including workover) phase for each of the facilities, which form part of the present hazard and risk assessment.

The qualitative risk assessment presented in Sections 4.1 to 4.6 below considered the cumulative risk during operation and maintenance for all wells, gathering systems, FCFs, CGPFs, IPFs and high pressure gas pipelines respectively. The risk for each individual facility would hence be much lower than what is stated in the present report.

4.1 COAL SEAM GAS WELLS

4.1.1 Hazardous Materials

The inventory, for each class of substances listed in the Australian Dangerous Goods Codes, to be held on-site during design and construction of gas wells is listed below:

Table 18 – Potentially Hazardous Chemicals Used During Well Operation

Hazardous Materials Product Name (Shipping Name)	HazChem / UN Number	Forecasted Project Quantity	Colour Rating as Provided By Arrow Energy
Petrol (Petrol)	3YE / 1203	160 litres	Amber
Mortein Lure and Kill High Performance Surface Spray Aerosol (Aerosols)	2Y / 1950	<3kg	Amber
Various solvents and thinners	2YE or 3YE / various	<100 litres / kg	Amber

Specifications, for the safe handling and storage of these materials, include bunding and ventilation arrangements, control of ignition sources, and requirements for personal protective equipment. Arrow has an occupational health and safety management system, which includes policy and procedures for the management of these types of hazards, including the need to establish internal audit and monitoring protocols. Provided that the internal (Arrow) and external (Dangerous Goods) requirements are followed the risks associated with these materials is very minor.

4.1.2 Hazardous Incident Scenarios

The hazardous incident scenarios relating to the operation of gas wells are associated with the following potential incident scenarios:

- Loss of containment of flammable gas causing equipment damage or injury from the high pressure event.
- Loss of containment of flammable gas with an ignition source present within the flammable dimensions of the released gas causing a jet fire or a flash fire.
- Fire at the electrical generator (where fitted) involving lubrication oils used in pumps.
- External event such as bush fire threatens people, plant and equipment located at the well compound(s) or on their way to or from the compound(s).
- Injury due to loss of containment of saline water, diesel or oil.
- Malfunction of electrical equipment causing electrocution or generation of a possible ignition source leading to a fire in case of subsequent release of flammable gas.

- Ignition of dry grass or brush caused by vehicle access to track causes bush fire during operation.

The potential hazards associated with periodic maintenance (including during workovers) are listed below:

- Ingress of air into process piping with flammable gas and an ignition source present causing internal fire/explosion.
- Fire incident involving inappropriate use of portable site flare or gas released during blowdown, which catches fire.
- Operator injury and equipment damage due to pressure burst.
- Well pump failure.
- Injury to workers due to handling of heavy machinery or equipment, working from height, or from handling of excessively hot or cold objects.
- Injury to driver due to transportation risks.
- Injury due to loss of containment of liquid hazardous materials or saline water.
- Injury due to electrocution.
- Confined space hazards to operators and contractors.

The potential hazardous consequences and associated mitigating strategy of the above scenarios are listed in Table 19 below. The risks (after application of controls) have been ranked in accordance with the risk matrix.

The risks associated with the operation and maintenance of wells are ranked at between *Low* risk and *High* risk, as per the definition in the risk matrix (Refer Appendix 4). Further information on the risk management controls, is provided in Appendix 2.

The risk is rated as the combined risk for all gas wells at all locations. The risk per well would be much lower, probably by at least one (or two) levels.

Table 19 – Hazardous Incident Word Diagram – Operation and Maintenance of Gas Wells

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Well Operation					
Loss of containment of flammable gas causes equipment damage or injury (from high pressure event) or, if ignition source present, a fire.	Loss of containment from well head or associated piping due to breach of structural integrity (pipe breach, flexible coupling, flange leak) or overpressure event due to control system failure or well shut-in / blocked outlet.	**Prevention:** Reinforced steel hoses or other high integrity material used for flexible connections. PM program and Standard Operating Procedures (SOPs) incl. Occupational Health and Safety Management Standard (OHSMS). Impact damage prevented through restricted vehicle. Flow and pressure instrumentation transmit upset condition. Maintenance of facility (in accordance with relevant standards) to cope with max pressures upstream of the remote operated shut-in valve. All pipes and vessels will be designed to cope with maximum pressure. Pressure transmitter with High and Low pressure alarms. **Protection:** Manual isolation valves at well and skid edge. Remote control isolation on gas and water lines. Fire breaks created from clearing of area around the wells (separate vegetation from wells). No enclosed spaces available at the wells - lighter than air gas rises quickly above ground. **Detection:** Manual gas detectors used by person working in well area. High and low pressure alarms to control room. **Control of ignition sources:** Electrical equipment as per hazardous zone requirements. Maintenance of electrical equipment as per PM program requirements. OHSMS including Permit To Work (PTW) system. Non-static clothing worn.	Major	Unlikely	Medium Risk

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Fire at the electrical generator involving lubrication oils used in pumps	Fire damaging equipment. Possible initiation of bush/brush fire.	**Prevention:** Operating procedures and design of equipment. Use of oils that are combustible only (not easily ignitable). Fire breaks management. **Protection:** Separation distances and layout. Fire extinguishers in vehicles. Fire extinguisher(s) at well-site compound. **Control of ignition sources:** Electrical equipment as per hazardous zone requirements. OHSMS including Permit To Work (PTW) system. Restricted zone requirements. Non-static clothing worn.	Minor	Rare	Very Low Risk
External event such as bush fire threatens people, plant and equipment at the well compound or on their way to or from the compound.	External event such as a bushfire impacting on the well site and possibly on people working at the site causing injury, fatality and/or damage to equipment. Damaged equipment may release flammable gas which would burn.	**Prevention:** Fire breaks through vegetation management around facilities. Design of equipment to withstand considerable heat load, e.g. through use of heat resistant (fire safe) isolation valves. **Protection:** Emergency Response Plan (ERP). Communication (mobile phones) available for people working on-site. Establishment of lone worker protocols and communication. Establishment of protocols when working during times of bush fire.	Severe	Rare	Medium Risk

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Injury due to loss of containment of saline water, diesel or oil.	Injury due to exposure to potentially hazardous material.	**Prevention:** Design of facility (in accordance with relevant standards). Preventative Maintenance (PM) program and Standard Operating Procedures (SOPs). Field Safety Management System. Fenced area, no vehicles allowed inside fenced area (minimising risk of damage and subsequent leak from equipment). Reinforced steel hoses or other high integrity material. Design and protection of pipes used for saline water to prevent damage. Well compounds are fenced to prevent unlawful access. **Protection:** Manual isolation valves at well and skid edge. Portable bunds used during transferring oil or diesel. Requirements for supervision during oil and diesel transfers. Drip trays under generators and generators are enclosed. ERP for major spill. **Detection:** Flow and pressure instrumentation to transmit upset condition. High and low pressure alarms to indicate upset major condition. ERP includes requirements for removal of contaminated soil. Plant inspection.	Moderate	Unlikely	Medium Risk

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Malfunction of electrical equipment causes electrocution or a possible ignition source leading to a fire.	Injury to maintenance worker. Possible ignition of combustible materials in the vicinity (leaf litter and other combustible vegetation). If release of flammable gas coincides with the electrical fault then possible fire.	**Prevention:** Design of facility in accordance with relevant standards. PM program and SOPs including OHSMS. Hazardous area classifications and electrical equipment designed accordingly. Personnel and contractors working on electrical equipment will be suitably trained. OHSMS including PTW system. **Protection:** PPE. Suitable equipment used.	Moderate	Rare	Low Risk
Ignition of dry grass or brush caused by vehicle access to track causes bush fire during operation	Construction and use of the access track would cause vegetation and ground cover clearance and potential for erosion, dust being generated and weed spreading. Access by vehicles on the access track could cause brush and bush fire.	**Prevention:** Track selection to avoid sensitive environmental areas. Track maintenance in accordance with SOP. Speed limits (minimises dust generation and deterioration). Vehicle weed control. Use of designated track only. Fire prevention SOP. **Protection:** Fire extinguisher in vehicle.	Moderate	Unlikely	Medium Risk

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Well Maintenance					
Ingress of air into process piping may cause internal fire/explosion if flammable gas and an ignition source is present.	Failure of safe purge procedure during commissioning or maintenance and subsequent start-up with flammable gas and air present inside process piping. If ignited (e.g. through statics) then possible fire or explosion inside of process equipment.	**Prevention:** This scenario is only theoretically possible during start-up, shut-down and maintenance operations; Piping normally operated at a positive pressure, preventing ingress of air; Procedures and maintenance/workover procedures including requirements for purging; Piping earthed. No credible ignition sources identified. Prevention of ingress of air will be considered throughout the design and operation of the facility (for example in the preparation of start-up, shut-down and maintenance procedures).	Moderate	Rare	Low Risk
Safety risk from holes, ditches, uneven terrain, heavy vehicles, working in isolation.	Operator injury	General safety precautions such as PPE, high visibility vests worn, speed limits, training and procedures apply. Policy and procedures for *lone worker*.	Moderate	Possible	Medium Risk
Fire or explosion risk	Ignition of flammable or combustible material; incident involving inappropriate use of site flare or gas released during blowdown catches fire causes injury or fatality, destruction of property.	**Prevention:** Fire and/or smoke alarms fitted, included in all relevant procedures, i.e. BOP procedure, BOP procedures and drills, site training and induction, HSE Audits and inspections, designated smoking areas, Hazardous Zones defined and enforced. **Protection:** Extinguisher servicing/inspection, Emergency response plan and fire drills.	Severe	Rare	Medium Risk

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Operator injury and equipment damage due to pressure burst.	Failure of formation pressure control and well control; blowout (swabbing, low fluid viscosity); extreme down hole losses, damage to wellhead equipment; free gas in wellbore due to blockage in existing well or laterals - potential gas pocket; circulation piping failure including during pressure testing; well becomes alive during operation (failure of barriers); over pressure system (e.g. blockage) resulting in sudden release of pressure.	**Prevention:** Key personnel maintain current well control certification; training of maintenance staff; use of correct tool; use of PPE; issuing of PTW; all equipment certified and procedure in place; **Protection:** Strength of equipment design. Emergency Response Procedure.	Moderate	Possible	Medium Risk
Well pump failure	Mechanical failure, seal leaks causes an incident at the well which leaks to injury.	The pumps are located at the bottom of the well within the gas stream, hence a leak at the casing or at the seal will release gas into the bottom of the well and not at the surface. Pumps, where fitted, have an automatic pump shutdown in case of pumping against a blockage. Regular and periodic pump inspections and preventative maintenance program, including seal integrity checks.	Minor	Unlikely	Low Risk
Injury to workers due to handling of heavy machinery or equipment, working from height, or from handling of excessively hot or cold objects.	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.	**Prevention:** PTW, JSEA's, visits/audits health, safety and environment advisors, warning signs, Life Saving Rules have height safety requirement, Pre Start inspection, tag lines to be used on all suspended loads, inspection / register of harnesses and height safety equipment and anchor points, process to clear area during perforating activities, housekeeping, locking pins for workover rig. **Protection:** Machinery guarding, appropriate PPE worn, personal fall arrest equipment, Wrist straps and lanyards to secure tools to be used at heights. Emergency procedures/drills, first aid trained personnel on site.	Moderate	Likely	Medium Risk

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Injury to driver due to transportation risks during well site access.	Driver inexperience, fatigue, excessive speed for conditions, mechanical failure, environmental conditions (dust, rain, sunlight), wildlife / livestock on roads, road surface condition e.g. rocks, potholes, loose gravel, road works and associated machinery, traffic management, cement and construction trucks, school bus hours.	Audits /Inspections of Procedures and Equipment by health, safety and environment advisors, drive to road conditions, Preventative Maintenance program, driver Training and Assessment in Safe Vehicle SOPs for Remote Locations, clearly defined Transport Management policy and procedures, supervision, s, detailed route planning including nominated rest stops, heat stress management procedures, State Law and Arrow lifesaving rules.	Moderate	Almost certain	High Risk
Injury due to loss of containment of liquid hazardous materials or saline water.	Loss of containment from storage or during handling of chemicals, e.g. during unloading or transfer causes injury to personnel or contractors from exposure if spill is not appropriately contained and cleaned up.	**Prevention:** SOPs developed for occupations that work with hazardous substances, training of personnel (personnel responsible for unloading chemicals are certified to operate equipment, audits and inspections, suitable storage facilities available following Code requirements, MSDS available, covered in the HSE Induction, legislative requirement for DG Transportation, dedicated cargo handling and storage area, that is cleared of all personnel, signs, HSE Advisers regularly audit this area. **Protection:** PPE, spill kits, Emergency Response Plan and local HAZMAT response plan in the event of a spill.	Moderate	Unlikely	Medium Risk
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:** planned maintenance of electrical equipment, correct grounding of electrical circuit, and HSE Audit	Moderate	Rare	Low Risk

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Confined Space hazards to operators and contractors	Asphyxiation and dermal absorption hazards in case of access to cellar, mud pits and water tanks.	**Prevention:** PTW system, HSE Audits and Advice, appropriate equipment provided, specialised training, (JSEA) for all confined space entry jobs, confined space entry training, contained within the Arrow safety management system (*lifesaving rules*).	Moderate	Rare	Low Risk

4.2 GATHERING SYSTEM

4.2.1 Hazardous Materials

No chemicals or other dangerous goods will be required for the operation of the gathering system.

4.2.2 Hazardous Incident Scenarios

The following potential incidents were identified for the gathering system:

- Loss of containment of flammable gas causes equipment damage or injury from the high pressure event.
- Loss of containment of flammable gas causes a fire if an ignition source is present.
- Ingress of air into gathering line piping may cause internal fire/explosion.
- Threat to people, plant and equipment due to external event such as bush fire.
- Electrical energy incident involving power lines.
- Ignition of dry grass or brush during vehicle access to track causes bush fire during operation and maintenance, leading to threat to people.

The following types of incidents may trigger a release from the gathering system. The approximate contribution to the overall failure rate of each type of initiating event (or trigger) are based on the data gathered by the European Gas pipeline Incident data Group, (Ref 27) between 1970 and 2007. This data source has been chosen based on the extensive statistical significance of the data available (1,470,000 kilometre-years)[4] and because of the similarities between the Australian Standard requirements and the requirements used in the European countries included in the incident statistics (including Britain, Belgium, France, Netherlands, Ireland, Portugal, Finland, Sweden, Switzerland, Germany):

- External interference: historically around the world, this accounts for about 40% of all incidents, caused by digging or trenching.
- Construction defect / material failure: about 15% of all incidents.
- Corrosion: about 15% of all incidents in steel pipelines, resulting in pinholes and cracks. Corrosion is not a concern for HDPE and GRE pipelines – however, other types of material defects and erosion issues are present in this type of pipeline. If steel pipelines are to be used in the medium pressure system then corrosion would apply.
- Ground movement: about 5% of all incidents.
- Hot tap by error: about 15% of all incidents.
- Other / unknown causes: Rare or unknown causes form about 10% of all historical incidents. They are mainly of the pinhole crack category.

While most of this data relate to steel pipelines in high-pressure service the learnings from these incidents can be applied also for HDPE and GRE pipelines such as that used for the

[4] As a comparison, the available statistics in Australia are based on (only) 160,000 km-yrs. The available statistics from the US Dept of Transportation Office of Pipeline Safety is based on 970,000 km-yrs but the standards used in the US are believed to be further from the Australian standards than those in use in Europe (as included in the EGIG).

gathering system[5]. The potential hazardous consequences and associated mitigating strategy of the above scenarios are listed in the table below. The risks (after application of controls) have been ranked in accordance with the risk matrix presented in Appendix 4.

Most risks associated with the operation and maintenance of wells are ranked as of Low risk, certain scenarios are ranked as of Medium or High risk as per the definition in the risk matrix.

The risk is rated as the combined risk for all gathering lines at all locations. The risk per measurement of gathering line would be much lower, probably by at least one (or two) levels.

While the management of risks associated with each scenario is summarised in the third column of the above table (*Required Controls*) some further information is provided in Appendix 2.

[5] Note that the percentages of each type of failure for steel pipelines would be different for HDPE and GRE pipelines.

Table 20 – Hazardous Incident Word Diagram, Operation and Maintenance - Gathering Systems

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Loss of containment of flammable gas causes equipment damage or injury (from high pressure event) or, if ignition source present, a fire (if the gas was confined this scenario may cause an explosion).	Breach of structural integrity of gathering system (3rd party activity, construction defect, material, integrity management failure, earthquake, ground movement etc.). If the control of ignition source fail then this scenario may cause fire (if gas is allowed to enter confined area then this may cause an explosion). Event may cause equipment damage or injury due to high pressures.	**Prevention:** Isolation valves (manual) installed. Design of gathering system (in accordance with relevant standards). Pipe signage, landowner liaison, depth of cover, standard installation practice, registration of Arrow assets with "dial before you dig". Regular patrols. **Protection:** Buried pipeline - gas release is dissipated. Natural gas is lighter than air and will rise quickly to altitude.	Major	Unlikely	Medium Risk
Ingress of air into gathering line piping may cause internal fire/explosion.	Failure of safe to purge procedure during commissioning or maintenance and subsequent start-up with flammable gas and air present inside piping. If ignited (e.g. through statics) then possible fire or explosion inside of process equipment.	**Prevention:** This scenario is possible during start-up, shut-down and maintenance operations; Piping is normally operated at a positive pressure, preventing ingress of air. Further, isolation valves will be shut in case of maintenance or cut-in operation for new piping. Commissioning procedures and maintenance procedures including requirements for purging; Piping is earthed. Provided hot work permit requirements followed, no credible ignition sources identified. Prevention of ingress of air will be considered throughout the design and operation of the facility (for example in the preparation of start-up, shut-down and maintenance procedures).	Moderate	Rare	Low Risk

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Threat to people, plant and equipment due to external event such as bush fire or remote area access / working in isolation.	External event such as a bushfire or vehicle accident impacting on the on people working at the site or accessing the site, causing injury. A bushfire may impact on above ground facilities such as vents could cause damage to equipment leading to release of flammable gas, which would burn.	**Prevention:** Pipelines are buried to a minimum depth of 750mm - insulation afforded by soil cover precludes damage from bushfire heat radiation, even for non-flowing pipeline. Above ground facilities and vents are metallic which provides some resistance to a fire. Control of activities during extreme fire danger periods. Audits /Inspections of Procedures and Equipment by health, safety and environment advisors, drive to road conditions, Preventative Maintenance program, driver Training and Assessment in Safe Vehicle SOPs for Remote Locations, clearly defined Transport Management policy and procedures, supervision, s, detailed route planning including nominated rest stops, heat stress management procedures, State Law and Arrow lifesaving rules. Speed limits, training and procedures apply. Policy and procedures for *lone worker*. **Detection:** Visual inspection of power lines and above ground facilities after bushfire. **Protection:** SOPs and emergency procedures.	Major	Unlikely	Medium risk
Electrical energy incident involving power lines.	Storms or high wind event causes damage to power lines. May cause electrocution or bushfire. Third party activity damaging power lines. May cause electrocution or bushfire.	**Prevention:** Electricity Industry Standards for design and construction of above ground power lines. Signage and registration of Arrow Energy assets with "dial before you dig". Landowner liaison. Marker tape. Third party crossings managed. "Tiger tails" on overhead power lines in areas with higher risk of crossing. **Detection:** Visual inspection as per Standard Operating Procedures.	Moderate	Rare	Low Risk

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Access track causes environmental impact or bush fire during construction, use and maintenance.	Construction and use of the access track would cause vegetation and ground cover clearance and potential for erosion, dust being generated and weed spreading. Access by vehicles on the access track could cause brush and bush fire.	**Prevention:** Track selection to avoid sensitive environmental areas. Track maintenance in accordance with SOP. Speed limits (minimises dust generation and deterioration). Vehicle weed control. Use of designated track only. Fire prevention SOP. **Protection:** Fire extinguisher in vehicle.	Moderate	Unlikely	Medium Risk

4.3 FIELD COMPRESSION FACILITIES

4.3.1 Hazardous Materials

There will be dangerous goods storages required for FCFs.

4.3.2 Hazardous Incident Scenarios

The risk associated with the Field Compression Facilities (FCFs) is predominantly related with the handling and compression of flammable gas, as follows:

- Loss of containment of flammable gas causes equipment damage or injury from high pressure event.
- Loss of containment of flammable gas with subsequent ignition causes fire or explosion (the latter is only credible in the case of confinement of flammable gases).
- Ingress of air into piping causes internal fire/ explosion.
- External event such as bush fire, lightning or flood poses a threat.
- Injury to personnel from damaged rotating machinery.
- Injury due to exposure to saline water, diesel or lube oil to subsurface, groundwater or ground.

The potential hazardous consequences and associated mitigating strategy of the above potential incident scenarios are listed in Table 21 below. The risks (after application of controls) have been ranked in accordance with the risk matrix presented in Appendix 4.

Most risks associated with the operation and maintenance of FCFs are ranked as of Low risk, certain scenarios are ranked as of Medium risk. While the management of risks associated with each scenario is summarised in the third column of the above table (*Required Controls*) some further information is provided in Appendix 2.

Table 21 – Hazardous Incident Word Diagram, Operation and Maintenance - Field Compression Facility

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Loss of containment of flammable gas causes equipment damage or injury (from high pressure event) or, if ignition source present, a fire.	Breach of structural integrity pipes. If the control of ignition source fail then this scenario may cause fire (if gas is allowed to enter a confined building then this may cause an explosion). Event may cause equipment damage or injury due to high pressures.	**Prevention:** Design of facility in accordance with relevant standards. PM program and SOPs including field OHSMS, conducted for risks associated with location and threat assessment. Impact potential minimised through fenced area and access controls to facility. **Minimising risk of enclosing CSG:** No enclosed spaces (compressors in open sheds). CSG is lighter than air and tends to rise rapidly to heights well above ignition sources where it disperses to below its lower flammable limit. **Control of ignition sources:** Hazardous area classifications (zone rated). Electrical equipment designed to Australian Standards requirement for equipment in potentially hazardous locations. PM of electrical equipment. PTW system. Non-static clothing worn. Establishment and maintenance of fire breaks to prevent brush/bush fires. **Protection:** Facility layout to stop propagation. Automated ESD system including remote monitoring and control. **Detection:** Flow and pressure instrumentation to transmit upset condition and plant shutdown valves. Fire/gas detection system around compressors to shutdown compressors. Security controls (fencing, locked gates).	Major	Unlikely	Medium Risk

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Ingress of air into process piping may cause internal fire/explosion.	Failure of safe purge procedure during commissioning or maintenance and subsequent start-up with flammable gas and air present inside piping. If ignited (e.g. through static electrical spark) then possible fire or explosion inside of process equipment.	**Prevention:** This scenario is possible during start-up, shut-down and maintenance operations; Piping normally operated at a positive pressure, preventing ingress of air; Commissioning procedures and maintenance procedures including requirements for purging; Piping earthed. Prevention of ingress of air will be considered throughout the design and operation of the facility (for example in the preparation of start-up, shut-down and maintenance procedures). **Recommendation:** Standards for O^2 purging to be set up (as new lines and wells are frequently being commissioned, oxygen may be an issue).	Moderate	Rare	Low Risk
Fire exerted from flaring activity	Flare becomes an ignition source resulting in bushfire or brushfire.	**Prevention:** Exclusion zone around flare based on radiation contour calculation as per API standard. Site selection. Establishment of fire breaks. CSG is lighter than air and would rise quickly above ground. Gas is flared at pressure (upward flow). No condensate or other combustible/flammable liquid dropouts.	Moderate	Rare	Low Risk
External event such as bush fire, lightning or flood poses a threat	Bushfire or lightning strike causes damage to facility from fire and heat radiation and possible ignition of flammables/combustibles. Flooding of site restricts access and removes ability for maintenance and for intervention.	**Prevention:** Establishment of fire breaks around facilities to minimise threat from bush fire. Design (in accordance with relevant standards) including lightning mast and earthing grid to minimise risk of lightning strike. Control of flooding risk through site location, build up site, Remote operation minimises exposure potential. Application of State Planning Policy 1/03, Mitigating the Adverse Impact of Flood, Bush Fire and Landslide. **Protection:** ERP.	Moderate	Rare	Low Risk

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
Injury to personnel from damaged rotating machinery	Injury to personnel and damage to equipment from internal component failure of rotating machinery.	**Prevention:** Design of facility (in accordance with relevant standards). Operating procedures. Preventive maintenance plan. Machine guarding.	Moderate	Rare	Low Risk
Exposure to saline waters, lube oil to subsurface, groundwater or land.	Loss of containment from saline waters or lube oil causes injury or property damage.	**Prevention:** Design of system (in accordance with relevant standards). Appropriate drainage of wastes through design and operation. Concrete floor with floor drainage system for small spills within building. **Protection:** Bunded storage area (in accordance with relevant standards). Compressors are bunded. Disposal as per approved method. ERP. **Detection:** Regular monitoring and reporting requirements. External monitoring bores.	Moderate	Possible	Medium Risk

4.4 CENTRAL GAS PROCESSING FACILITIES

4.4.1 Hazardous Materials

TEG is classified as combustible only and hence does not have a Dangerous Goods Code[6] in accordance with the *Australian Dangerous Goods Code* (Ref 33). As such it are not readily ignitable. It is however held under high temperatures and has therefore been listed below:

Table 22 – Major Storages for Use During Operation of CGPFs

Hazardous Materials Product Name (Shipping Name)	HazChem / UN Number	Forecasted Project Quantity	Colour Rating as Provided By Arrow Energy
Triethylene Glycol (no shipping name available)	N/A	10,800 litres	Amber

TEG is used for drying the gas before it enters the compressors. It has a very low order of acute toxicity by inhalation (the potential for vapour and aerosol generation is low). It does not produce primary skin irritation. Acute eye contact with the liquid causes mild local transient irritation but does not induce corneal injury. The properties of ethylene glycol are listed in below:

Table 23 – Properties of Tri-Ethylene Glycol

Boiling point at 1 atm (°C)	285
Melting point (°C)	-7.2
Vapour pressure (at 1 atm)	<0.1 mm Hg
Specific gravity (water = 1)	1.1
Flammable limits (vol. % in air)	0.9 – 9.2
Flash point (°C)	168-177

AS1940:2004 – *Storage and handling of flammable and combustible liquids* (Ref 28) provide detailed requirements for the safe storage and handling of these combustible materials. Provided the requirements under this standard are followed, the risk associated with liquid combustible materials held at the facilities is nominal.

4.4.2 Hazardous Incident Scenarios

Hazards at CGPFs may arise relating to fixed plant, storage, and pipelines. The main risk associated with the CGPFs, as per the FCFs, are related with the handling and compression of flammable gas, as follows:

- Loss of containment of flammable gas causes equipment damage or injury from high pressure event.
- Loss of containment of flammable gas with subsequent ignition causes fire or explosion (the latter is only credible in the case of confinement of flammable gases).
- Ingress of air into piping causes internal fire/ explosion.
- External event such as bush fire, lightning or flood poses a threat.

[6] Combustible liquids are liquids that burn, but are more difficult to ignite than flammable liquids. They have a flashpoint greater than 60.5°C and are not classified as dangerous goods (whereas liquids with a lower flashpoint are dangerous goods Class 3 – flammable liquids). C1 combustible liquids have flash points of <150°C while C2 combustible liquids have flash points >150°C. TEG therefore is classified as a C2 combustible liquid.

- Injury to personnel from damaged rotating machinery.
- Injury due to exposure to saline water, diesel or lube oil to subsurface, groundwater or ground.

These scenarios are detailed in Section 4.3 - *Field Compression Facilities* (above) and have not been repeated here. While it is acknowledged that the CGPFs will be larger and will include more compressors, more generators and more saline water storage areas, the risk rating for the potential incident scenarios at the FCFs is largely the same as for the CGPF.

Additional risks associated with the CGPFs (which are not relevant for the FCFs) of risks where the risk ranking is believed to be different for the CGPFs compared with the FCFs are:

- Fire risk due to ignition of TEG.
- Fire initiated from excessive flaring or from release to flare beyond design limits.

The potential hazardous consequences and associated mitigating strategy of the above *additional* potential incident scenario are listed in Table 24 below. The risks (after application of controls) have been ranked in accordance with the risk matrix presented in Appendix 4. While the management of risks associated with each scenario is summarised in the third column of the above table (*Required Controls*) some further information is provided in Appendix 2.

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Table 24 – Hazardous Incident Word Diagram, Operation and Maintenance - Central Gas Processing Facilities

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
All hazards and risks as discussed under FCFs are relevant also for the CGPF (also when installed within an IPF). Additional scenario, specific to the CGPFs (and to the IPFs) is:					
Fire or explosion risk due to ignition of TEG	Ignition of TEG causes injury or destruction of property.	**Prevention:** Fire and/or smoke alarms fitted, Operating procedures including purging requirements and hot work permits, site training and induction, HSE Audits and inspections, designated smoking areas, Hazardous Zones defined and enforced. Blow-out of pipes to clean from construction debris will be done using well established procedures and under strict controls, including those detailed in risk assessments. **Protection:** Extinguisher servicing/inspection, Emergency response plan and fire drills. Fire detection and shutdown (once commissioned)	Moderate	Unlikely	Medium Risk
Fire exerted from flaring activity	Flare becomes an ignition source resulting in bushfire or brushfire	**Prevention:** Exclusion zone around flare based on radiation contour calculation as per API standard. Height of flare is very high off the ground removing ignition source from fuel. Site selection. Vegetation management. Consistent gas composition. CSG is lighter than air and would rise quickly above ground. Gas is flared at pressure (upward flow). No condensate or other combustible/flammable liquid dropouts.	Moderate	Rare	Low Risk

4.5 INTEGRATED PRODUCTION FACILITIES

4.5.1 Potentially Hazardous Incidents

Each Integrated Production Facility (IPF) will incorporate one Central Gas Processing Facility (CGPF). Hence, the hazards associate with the CGPF, as discussed in Section 4.4 above, are relevant also for the IPFs and are not repeated in the following section. Only the additional hazards associated with the IPFs are discussed in this section.

The additional hazards and risks relating to the operation of the IPF's Water treatment facilities are associated with the following potential incident scenarios (note that these hazards are not relevant for the CGPFs):

- External event such as bush fire, lightning or flood poses a threat to Water treatment facility.
- Harmful exposure to water treatment chemicals (corrosives, toxics, biocides, oxidants).
- Drowning in dam.
- Failure of dam wall.
- Exposure to accidental, major release of brine water, CSG water, or treatment chemicals to subsurface, groundwater or land.

The potential hazardous consequences and associated mitigating strategy of the above potential incident scenarios are listed in Table 25 below.

The risks (after application of controls) have been ranked in accordance with the risk matrix (presented in Appendix 4).

Table 25 – Hazardous Incident Word Diagram, Operation and Maintenance - Integrated Processing Facilities

Hazard or Risk	Causes and Consequences	Required Controls	Consequences	Likelihood	Risk
Operation and Maintenance - CGPF					
All hazards and risks associated with the CGPF within the IPF, as discussed under Section 4.3 for the FCF above are relevant also for the IPFs.					
Operation and Maintenance – Power generation					
All hazards and risks associated with power generation, as discussed under Section 4.3 above are relevant also for the IPFs.					
Operation and Maintenance - Water Treatment Facility					
External event such as bush fire, lightning or flood poses a threat to Water Treatment facility.	Bushfire or lightning strike causes damage to IPF from fire and heat. Flooding of site restricts access, overflows dams, and removes ability for maintenance and for intervention.	**Prevention:** Fire breaks created through vegetation management around facilities to minimise threat from bush fire. Design (in accordance with relevant standards) including lightning mast and earthing grid to minimise risk of lightning strike. Control of flooding risk through site location, build up site, spare capacity in dam as per dam construction guidelines. Remote operation. Application of State Planning Policy 1/03, Mitigating the Adverse Impact of Flood, Bush Fire and Landslide. **Protection:** ERP.	Minor	Rare	Very Low Risk

Hazard or Risk	Causes and Consequences	Required Controls	Consequences	Likelihood	Risk
Harmful exposure to water treatment chemicals (corrosives, toxics, biocides, oxidants).	Injury or illness to operators due to exposure of harmful material released from process equipment or due to evolution of harmful/toxic gases if incompatible materials are allowed to mix, e.g. in drains.	**Prevention:** Design of system (in accordance with relevant standards). Use low-hazard chemicals where possible. No toxic gases used for water treatment (only liquids - a liquid loss of containment is easier to manage). Automated chemical dosage system. Training of operators in chemicals handling and development of SOPs. Signage, Segregation, Operator controlled unloading. Hazardous materials management and SOPs. Transport specifications for hazardous materials. Water treatment chemicals are in a separately fenced area from other chemicals. **Protection:** ESD points near the chemical storage area. Safety showers and eye-wash stations. PPE. Pipe insulation or hot pipes to OH&S standards. SOP. Fit for purpose transfer equipment.	Moderate	Rare	Low Risk
Failure of dam level management & integrity management causes injury or drowning	Possible fatality to staff member or third party	**Prevention:** Fencing, signage. Line banks of dam with textured HDPE (ridged material). Escape ropes. Ladders. Dam level management & integrity management systems.	Severe	Rare	Medium Risk

Hazard or Risk	Causes and Consequences	Required Controls	Consequences	Likelihood	Risk
Injury from loss of containment of brine water, CSG water, or treatment chemicals	Loss of containment from feed, brine and utility dams; or loss of containment from water treatment plant could result in injury	**Prevention:** Design of system (in accordance with relevant standards). Appropriate drainage of wastes through design and operation. Concrete floor with floor drainage system for small spills within building. PE lined dams; dam construction guideline issued by the Department of Environment and Resource Management (DERM), including overflow and operational controls; approved dams (by DERM); mandatory reporting levels; freeboard requirements. Design and installation of gathering lines for saline water to prevent damage (e.g. from impact or age). Preventative maintenance and inspection on a regular basis. **Protection:** Bunded chemical storage area (in accordance with relevant standards). Compressors are bunded. Disposal as per approved method. ERP. Paved and contained unloading areas. **Detection:** Regular monitoring and reporting requirements. External monitoring bores.	Moderate	Unlikely	Medium Risk

4.6 HIGH PRESSURE GAS PIPELINES

Hazards associated with the high pressure gas pipelines are identical to those identified for the Arrow Energy Surat Pipeline, as reported in the Environmental Impact Statement, Ref 2.

Further risks and risk management strategies, not discussed in the Arrow Surat Pipeline Environmental Impact Statement (Ref 2) are as follows:

Stress Corrosion Cracking (SCC) in pipelines is a type of environmentally-assisted cracking which reduces the pressure carrying capacity of a pipeline. If water (which acts as an electrolyte) is allowed to come into contact with the steel of the pipeline surface, the minerals, ions, and gases in the water can attack or corrode the steel. This may result in wall thinning, corrosion pits, and/or cracks. Environmentally assisted cracking is the generic term, which includes two mechanisms, namely Corrosion fatigue and SCC.

Arrow will manage the quality and effectiveness of factory applied pipeline coatings, of field applied pipeline coatings (such as tape wraps and heat shrink sleeves) through a quality control processes. Further, monitoring and maintenance regimes to ascertain the effectiveness of pipeline coatings in service will need to be established.

5 Qualitative Risk Assessment, Decommissioning and Rehabilitation

A qualitative risk assessment, using the risk matrix provided in Appendix 4, was conducted for the decommissioning phase for each of the facilities, which form part of the present hazard and risk assessment.

The qualitative risk assessment presented in Sections 5.1 to 5.4 below considered the cumulative risk during decommissioning for all wells, gathering systems, FCFs, CGPFs, IPFs and high pressure gas pipelines respectively. The risk for each individual facility would hence be much lower than what is stated in the present report.

The main hazard associated with decommissioning involves the failure to purge pipelines and pipe equipment prior to introduction of an ignition source (e.g. in the form of welding).

All plant and equipment in flammable gas use would be depressurised and degassed prior to decommissioning. Depressurising and purging activities would be carried out by suitably trained and supervised staff or contractors using procedures and formal systems in place to manage hazards and risks, including Job safety analysis and Permit To Work. Arrow safety management system would be in place. Some further details are listed below:

5.1 Coal Seam Gas Wells

5.1.1 Hazardous Materials

No chemicals are required to be used during decommissioning phases.

5.1.2 Potentially Hazardous Incidents

Wells are decommissioned when they reach the end of their useful life. All surface equipment is removed, and a drilling rig is used to cut the well casing off approximately 1000mm below the ground surface and the well is plugged with concrete.

A statutory signpost is erected on a nearby fence or other suitable structure indicating the presence of the abandoned well.

Rehabilitation may involve resurfacing ground levels regrading surface topsoils, ensuring erosion controls are in place, and re-establishing drainage lines and vegetation.

Few processes or activities have the potential to cause a major incident with the exception relating to the degassing and purging of pipes and equipment from flammable gas prior to conducting any hot work (such as welding or cutting).

Degassing and purging would be conducted by properly trained staff or contractors under Arrow supervision.

Further, all work where ignition sources may be present (i.e. hot work) would be conducted under a strict proceduralised Permit to Work regime, ensuring potential hazards have been identified and properly mitigated against and that communication, training and supervision of staff and contractors is adequate.

Provided the Safety Management System which will be established for this development is maintained, the risk associated with decommissioning the gas wells is considered to be low.

5.2 GATHERING SYSTEM

Decommissioning involves the pigging, purging and flushing.

Purging of flammable gas would be achieved using nitrogen or other inert gas carried out by suitably trained and supervised staff or contractors using procedures and formal systems in place to manage hazards and risks, including Job safety analysis and Permit To Work. A safety management system would be in place.

Decommissioning and rehabilitation of the gathering system will most likely be undertaken as a combined project activity. However, partial decommissioning and rehabilitation of one or more plant components is also possible. Decommissioning and rehabilitation works may not occur for many years yet (the GGS and the pipeline are designed for a 25 year operational life). Therefore the following principles are presented as guidelines.

The gathering system will be flooded and capped and remain below the ground surface. All associated signage will be removed. No land contaminating processes associated with the use of the gathering system are expected, as the pipelines will have carried only gas. Again, the most significant incident potential relate to the degassing and purging of the pipelines, with Hot Work Permits and adequate supervision and training requirements being applied, see above.

The hazardous incident scenarios relating to the decommissioning of the gathering system are the same as those listed under Design and Installation of the gathering system, in Section 3.2 above.

The risks (after application of controls) have been ranked in accordance with the risk matrix (in Appendix 4). The same risk ranking as for the design and installation (Section 3.2 above) apply.

Another risk associated with decommissioning of the gathering system relates to a failure in depressuring, purging and decontamination procedure which leads to either a major release of flammable gas or to ingress of air in flammable space within pipeline.

Table 26 – Hazard Identification Word Diagram, Design and Installation - Gathering System

Hazard or Risk	Causes and Consequences	Required Controls	Consequence	Likelihood	Risk
All potential incident scenarios as per Table 14 in Section 3.2 (above) for the Design and Installation of the gathering system. Further:					
Failure in depressuring, purging and decontamination procedure leads to major release of flammable gas or ingress of air in flammable space within pipeline.	Loss of containment of natural gas from the gas pipeline during purging and decontamination. Ingress of air into pipeline during purging and decontamination. Ignition of flammable gas leads to injury or destruction of property.	**Prevention:** Procedures including requirements for purging; Prevention of ingress of air will be considered throughout the design and operation of the pipeline (for example in the preparation of start-up, shut-down and maintenance procedures).	Moderate	Rare	Low Risk

5.3 FIELD COMPRESSION FACILITIES, CENTRAL GAS PROCESSING FACILITIES AND INTEGRATED PROCESSING FACILITIES

Decommissioning and rehabilitation of FCFs, CGPFs and IPFs may be undertaken as a combined project activity or as partial decommissioning and rehabilitation of one or more components. Decommissioning and rehabilitation works may not occur for 15 to 40 years. Therefore the following principles are presented as guidelines.

Few processes or activities have significant potential to cause a major incident, which could threaten the safety of people on or off site. As per the above, the most significant is the depressuring and degassing of pipes and process equipment, ensuring that they are free from flammable gas prior to conducting any work, which may involve an ignition source (hot work) such as cutting. Such activities would be performed under so called Permit to Work regimes, ensuring that the relevant hazards have been identified and properly mitigated against and that the level of training and supervision of people conducting the work is adequate.

Where part of a site is retained for one or more ongoing activities while part of the site is decommissioned, careful planning and assessment will be conducted ensuring that operational and decommissioning activities do not adversely affect each other.

The main potentially hazardous activity associated with decommissioning of a site is the depressuring and degassing of pipes and process equipment, and ensuring that they are free from flammable gas prior to conducting any work which may involve an ignition source (hot work) such as cutting. Such activities would be performed under so called Permit to Work regimes, ensuring that the relevant hazards have been identified and properly mitigated against and that the level of training and supervision of people conducting the work is adequate.

Provided the Safety Management System which will be established for this development is maintained, the risk associated with decommissioning the coal seam gas wells is considered to be low.

5.4 HIGH PRESSURE GAS PIPELINES

The high pressure gas pipelines will be flooded and capped and remain below the ground surface. All associated signage will be removed. No land contaminating processes associated with the use of the gathering system are expected, as the pipes will have carried only gas and water. Again, the most significant incident potential relate to the degassing and purging of the pipelines, with Hot Work Permits and adequate supervision and training requirements being applied, see above. The hazards and risks associated with decommissioning of the high pressure gas pipelines are the same as for the gathering system, as discussed in Section 5.2 above.

6 QUANTITATIVE RISK ANALYSIS

6.1.1 Introduction

The quantitative risk assessment is carried out for the operational stage of the proposed development in order to determine appropriate buffer zones between the proposed facilities and neighbouring land uses. Provided that the buffer zones determined for the operational phase are maintained, the distances between the facilities and neighbouring land uses will adhere to acceptable risk criteria for all stages of this development.

6.1.2 Isolation

Isolation around a leak is an important risk management measure for flammable gas incidents. There are a number of automatic trips associated with the facilities, which form part of the present development, in particular with the compressors. Isolation valves would close automatically around the compressors in case of a major leak in order to minimise the amount of gas that would be released in case of a leak. The emergency isolation valves can also be shut remotely for example in case of a release of gas or a fire on site.

However, as with all systems, an emergency isolation could fail (for example due to a failure of the trip mechanism or because of a failure of the valve itself) and the amount of flammable gas involved in the incident scenario could then be much greater, described as “infinite” in the table below.

The approach taken in this PHA to assume a limitation on the incident scenarios based on quantities of available gas between isolation valves for the most major[7] failure scenarios. Further, the PHA allocates a likelihood of failure of the emergency shutdown mechanism, in which case the amount of gas would be much greater[8] (for further details refer Appendix 4). Therefore, the calculations of the consequences and risk reported in the PHA (as proved in the consequence tables below) are not dependent on the quantities of gas between isolation valves. However, the risk assessment takes into account the probability of the automatic isolation being achieved.

Note that the approach taken of assuming an “infinite” release of gas in case of a major leak and where the automatic response fails is conservative. In reality, the gas wells will be monitored and emergency response will be able to be initiated. Further, if for example a pump at the gas well was to fail, the well would be flooded and the gas stream would be reduced and eventually stopped. However, in the absence of an automatic response, the release source is likely to develop in a *steady-state,* and the maximum effects of an ignition would be reached within say 10 minutes, well before manual response was able to be achieved and well before plant response such as flooding of a well would occur.

6.2 GAS WELLS

6.2.1 Results of the Consequence Analysis

The detailed results for each incident scenario included in this PHA are listed in Appendix 4.

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[7] In the QRA, *major* failure scenario is defined as a release covering 10% or more of the cross sectional area of a pipe or a massive hole in a vessel.

[8] The probability of failure of an automatic emergency isolation is set as 0.05 per demand (5%).

6.2.2 Individual Risk of Fatality

The hazardous consequences of a number of the scenarios identified for the proposed development have the potential to affect the areas outside the immediate well compound. However, due to the stringent risk management measures imposed, both legally through Codes and Standards, and through Arrow's internal systems, the likelihood of a major incident involving these facilities is very low (refer Appendix 4).

This equates to a low risk outside of the compound boundaries. The risk associated with a gas well compound is best represented as risk transects, showing the risk as a function of the distance away from the well head, as shown in the individual risk results presented in Figure 3 below. The risk transect would be approximately equal in all directions. The distance to a particular risk level is the radius of a circle with the gas well head at the centre.

Table 27 – Dispersion and Heat Radiation Modelling, Gas Wells

Size of Release	Release rate (kg/min)	Maximum amount of gas released (kg)	Threat zone[9] for non burning gas (distance to LFL) (m)	Threat zone for burning gas (jet fire) (m)		
				22 kW/m²	12 kW/m²	4.7 kW/m²
Wells Tubing						
Pipeline rupture	0.8	Infinite[10]	18	14	17	18
Major (10% of cross section of pipe)	0.1	Infinite[10]	16	3	6	12
Minor (10mm)	0.02	Lim. by pump capacity	<1	3	3	4
Wells Casing						
Pipeline rupture	4.9	Infinite[10]	25	26	30	40
Major(10% of cross section of pipe)	0.1	Infinite[10]	16	3	6	12
Minor (10mm)	0.02	Lim. by pump capacity	<1	3	3	4
Wells to Gathering Line						
Rupture	0.8	Infinite[10]	18	14	17	18
Major	0.1	Infinite[10]	16	3	6	12
Minor	0.02	Lim. by pump capacity	<1	3	3	4

[9] Refers to the maximum distance between Lower Flammable Limits of the CSG cloud. The maximum distances modelled listed here are relevant for low wind stable conditions mainly experienced during night time. Risk assessment takes into account the probability of each wind weather condition as per Section 1.4.5.

[10] The maximum amount of gas released is for the scenario where the automatic isolation valves and depressuring fails (about 5% of cases). In several of the cases, the amount is modelled as unlimited. In reality, emergency response procedures will be prepared to deal with these scenarios. If the automatic isolation and venting works as designed then this amount of gas is much smaller. The risk assessment takes into account both events.

Table 28 – Heat Radiation and Vapour Cloud Explosion, Gas Wells

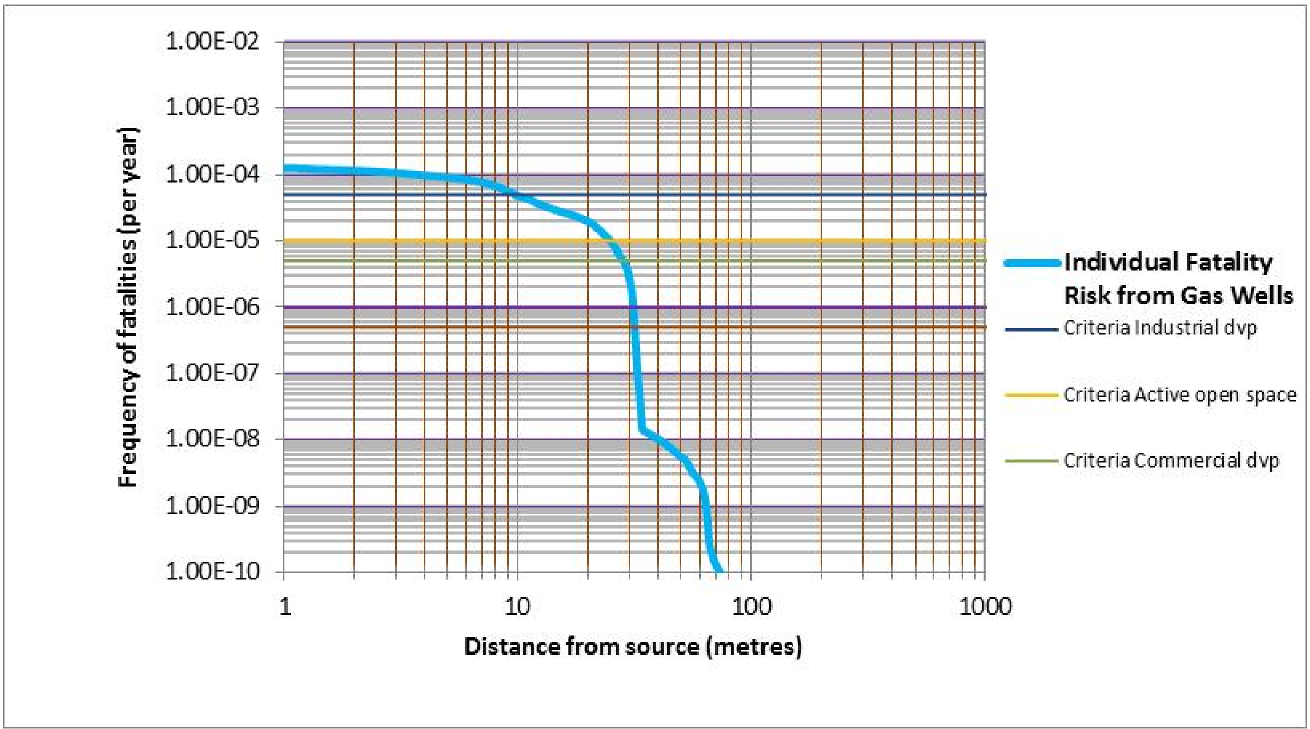
Size of Release	Amount of Gas in Flammable Cloud[11] (kg)		Threat Zone, Flash Fire[12] (m)
	D4	F2	
Wells Tubing			
Rupture	10	14	18
Major	<10	<10	16
Minor	<10	<10	<1
Wells Casing			
Rupture	<10	330	25
Major	<10	<10	16
Minor	<10	<10	<1
Wells Line towards the Gathering Line			
Rupture	10	14	18
Major	<10	<10	16
Minor	<10	<10	<1

Please note that Vapour Cloud Explosion is not considered a credible event for gas wells, as discussed in Section 1.4.3A.

[11] As per consequence modelling, maximum amount of gas in cloud is limited through outflow rate and dispersion characteristics.

[12] The probability of fatality from exposure to a flash fire is based on 100% of people within a vapour cloud concentration greater than the lower flammable limit (LFL).

Figure 3 - Individual Fatality Risk Transect for Coal Seam Gas Wells



NOTE: The distance from the source is measured from the centre of the well head.

Separation distances for the various types of land uses that may be found in the Surat Gas Project development area can be derived by setting the separation distance equal to the radius of the relevant fatality risk contour, taking into account sensitivity issues, as shown in the table below.

Please note that the Industrial Criteria applies to neighbouring industrial facilities and not to risk to workers at the well.

Table 29 – Coal Seam Gas Wells, Minimum Distance to Satisfy Land use Risk Criteria[13]

Wells	Minimum Buffer Distance (metres)				
	Industrial Buffer ($50x10^{-6}$/yr)	Active open space ($10x10^{-6}$/yr)	Business ($5x10^{-6}$/yr)	Residential development ($1x10^{-6}$/yr)	Sensitive development ($0.1x10^{-6}$/yr)
Well with flexible connections	10 metres	25 metres	30 metres	30 metres	35 metres

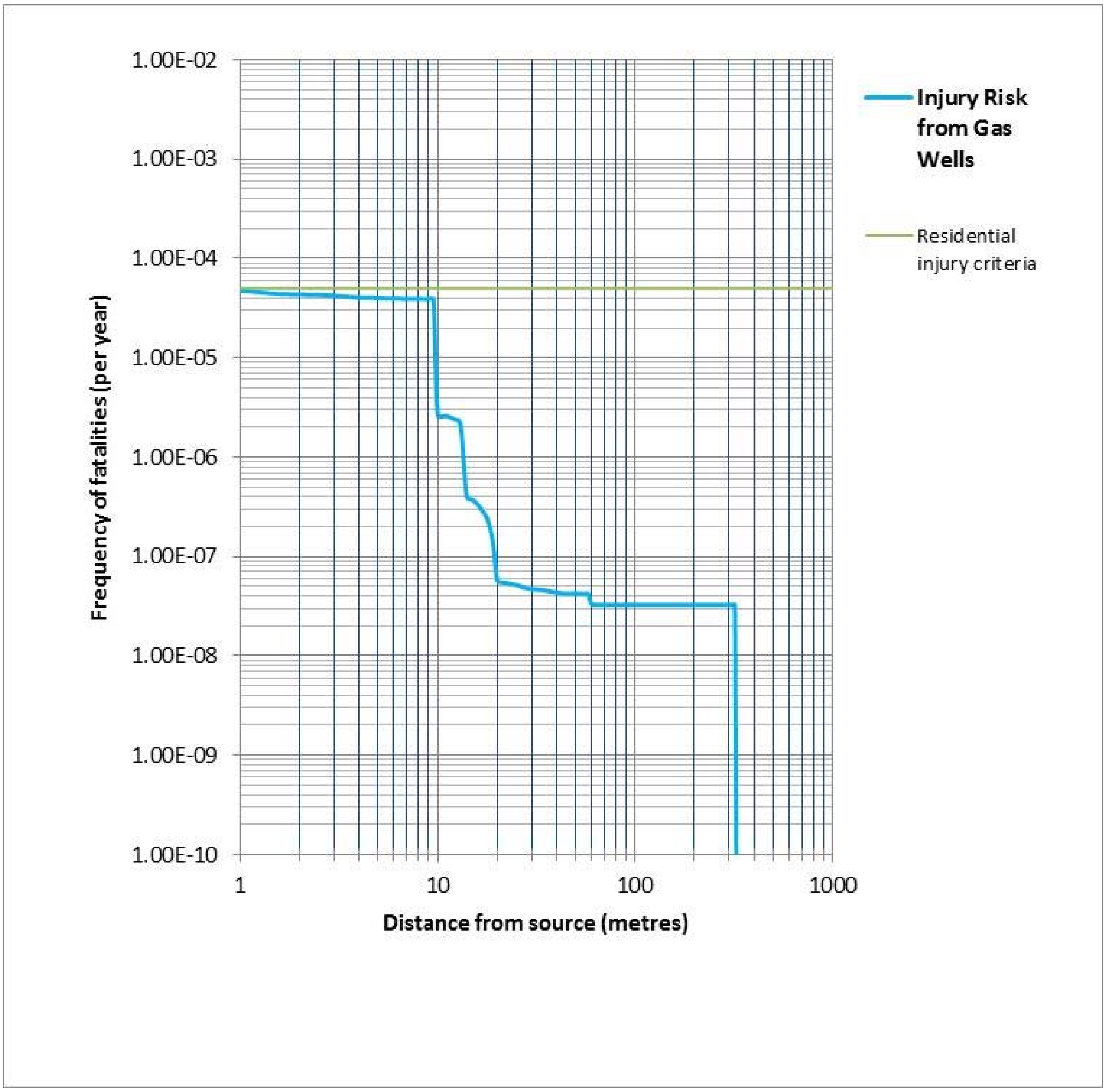
The level of risk associated with the development which is considered "tolerable" for residential housing is three times lower than the risk of being killed by a falling object or being electrocuted in an non industrial environment, and is about ten times lower than the risk of being killed in an aeroplane accident in Australia (or 145 times lower than being killed while travelling in a car).

[13] The minimum distances have conservatively been rounded up to the nearest 5, i.e. a calculated distance of 11, 12, 13, 14 or 15 metres would all be listed as of minimum distance to safety criteria of 15 metres.

6.2.3 Injury Risk

The risk of injury from a gas well incident is very small for off-site populations (Figure 4). The injury risk contour for gas wells is contained within the compound boundary thereby meeting the injury risk criteria.

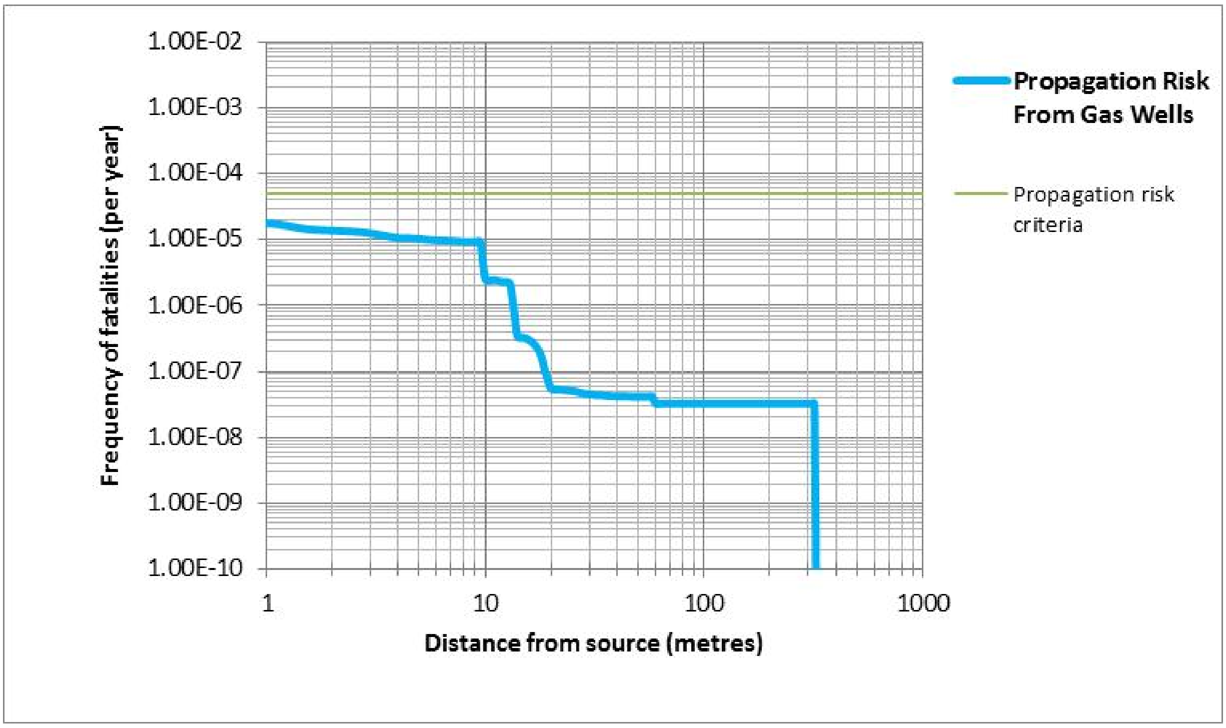
Figure 4 – Gas Wells Injury Risk



6.2.4 Propagation Risk

The propagation risk from a gas well is very small (Figure 5). The propagation risk contour is contained within the compound boundary thereby meeting the propagation risk criteria.

Figure 5 – Gas Wells Propagation Risk



6.3 GATHERING SYSTEM

6.3.1 Results of the Consequence Analysis

The detailed results for each incident scenario included in this PHA are listed in Appendix 3. A summary listing for the significant incident scenarios is provided in the table below. The scenarios do not take into account any isolation of the source of the gas to the gathering system and hence the release is *infinite.* In reality, the gas wells will be monitored and emergency response will be able to be initiated. However, in the absence of an automatic response, the release source is likely to develop in a *steady-state,* and the maximum effects of an ignition would be reached within say 10 minutes, well before manual response was able to be achieved and well before plant response such as flooding of a well would occur.

6.3.2 Individual Risk of Fatality

The risk associated with the gathering line is best represented as risk transects, showing the risk as a function of the distance away from the centreline of the gathering line, as shown in Figure 6 for the low pressure system and in Figure 7 for the medium pressure system. The distance from the centreline of the pipeline follows the route parallel to the pipeline.

Table 30 – Dispersion and Heat Radiation Modelling, Gathering System

Size of Release	Release rate (kg/sec)	Release Duration (seconds)	Threat zone[14] for non- burning gas (metres)	Distance to Heat Radiation (jet fire) (metres)		
			LFL[15]	22 kW/m^2	12 kW/m^2	4.7 kW/m^2
Gathering Line – Low Pressure – 100mm Diameter						
Rupture (100mm diameter)	2.7	Representative duration: 100 seconds[16]	5	4	6	7
10% Leak[17] (32mm equivalent diameter)	0.16	Infinite	3	<1	7	6
Minor Leak (20mm diameter)	0.07	Infinite	<1	<1	5	6
Gathering Line – Low Pressure – 630mm Diameter						
Rupture (630mm diameter)	99	Representative duration: 100 seconds[16]	65	35	45	60
10% Leak (199mm equivalent diameter)	7.6	Representative duration: 100 seconds[16]	20	25	35	47
Minor (20mm diameter)	0.08	Infinite	<1	<1	5	6
Gathering Line – Medium Pressure – 100mm Diameter						
Rupture (100mm diameter)	5.9	Representative duration: 100 seconds[16]	8	4	10	15

[14] Refers to the maximum distance to the Lower Flammable Limit of the CSG cloud. Calculated using TNO Effects v8.0.1 *Max conc. vs downwind distance.*

[15] Maximum distance listed here are relevant for low wind stable conditions mainly experienced during night time. Risk assessment takes into account the probability of each wind weather condition as per Section 1.4.5.

[16] As calculated by TNO Effects 8.0.1

[17] Hole size equivalent to 10% of the cross sectional area of the pipeline

Size of Release	Release rate (kg/sec)	Release Duration (seconds)	Threat zone[14] for non- burning gas (metres)	Distance to Heat Radiation (jet fire) (metres)		
			LFL[15]	22 kW/m^2	12 kW/m^2	4.7 kW/m^2
10% Leak[18] (32mm equivalent diameter)	0.3	Infinite	2	4	8	12
Minor (20mm diameter)	0.1	Infinite	<1	<1	6	10
Gathering Line – Medium Pressure – 630mm Diameter						
Rupture (630mm diameter)	421	Representative duration: 100 seconds[16]	190	75	100	140
10% Leak (199mm equivalent diameter)	14	Representative duration: 100 seconds[16]	15	50	70	90
Minor (20mm diameter)	0.14	Infinite	3	<1	7	11

[18] Hole size equivalent to 10% of the cross sectional area of the pipeline

Table 31 – Heat Radiation and Vapour Cloud Explosions, Gathering System

Size of Release	Amount of Gas in Flammable Cloud[19] (kg)		Threat Zone, Flash Fire[20] (m)
	D4	F2	
Gathering Line – Low Pressure – 100mm Diameter			
Rupture	<10	<10	5
Major (10%)	<10	<10	3
Minor	<10	<10	<1
Gathering Line – Low Pressure – 630mm Diameter			
Rupture	154	740	65
Major (10%)	175	23	20
Minor	<10	<10	<1
Gathering Line – Medium Pressure – 100mm Diameter			
Rupture	<10	1	8
Major (10%)	<10	<10	2
Minor	<10	<10	<1
Gathering Line – Medium Pressure – 630mm Diameter			
Rupture	1431	1865	190
Major (10%)	43	50	15
Minor	N/A	N/A	3

Please note that Vapour Cloud Explosion is not considered a credible event for gas wells, as discussed in Section 1.4.3A.

[19] As per consequence modelling, maximum amount of gas in cloud is limited through outflow rate and dispersion characteristics.

[20] The probability of fatality from exposure to a flash fire is based on 100% of people within a vapour cloud concentration greater than the lower flammable limit (LFL).

Figure 6 – Individual Risk Transect for Low Pressure Gathering System

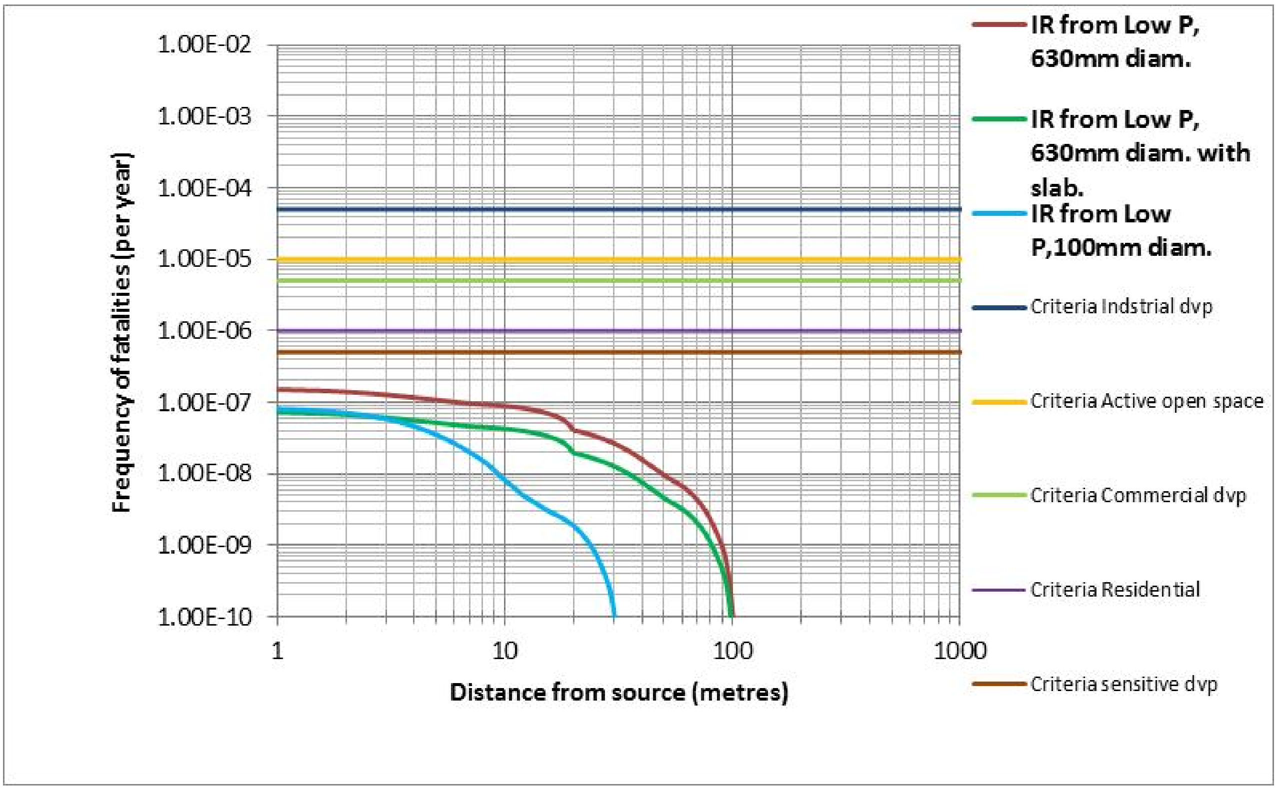
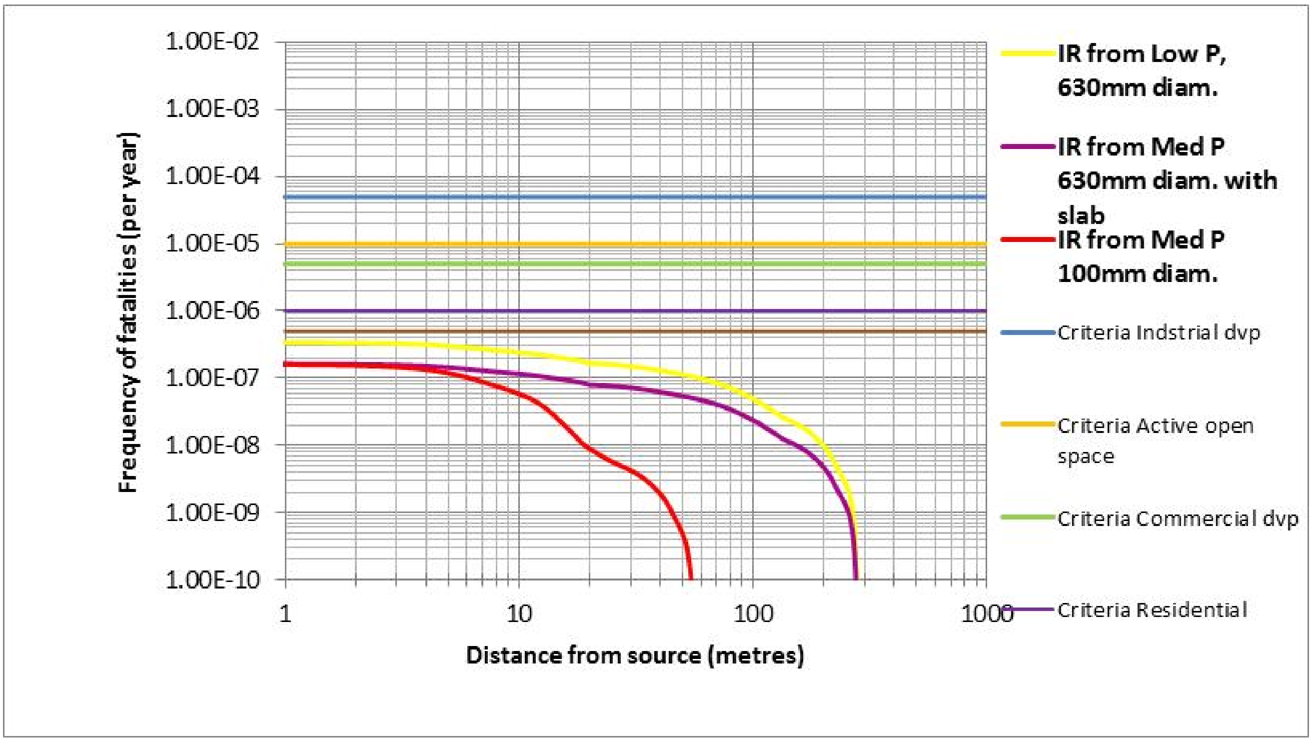


Figure 7 – Individual Risk Transect for Medium Pressure Gathering System



Separation distances for the various types of land uses that may be found in the Surat Gas Project development area can be derived by setting the separation distance equal to the radius of the relevant fatality risk contour, taking into account sensitivity issues, as shown in Tables 33 and 34.

Table 32 – Low Pressure Gathering System, Minimum Distance to Satisfy Land use Criteria[21]

Low Pressure Gathering System	Minimum Buffer Distance (metres)				
	Industrial Buffer (50 x 10^{-6} /yr)	Active open space (10 x 10^{-6} /yr)	Business (5 x 10^{-6} /yr)	Residential development (1 x 10^{-6} /yr)	Sensitive development (0.1 x 10^{-6} /yr)
Small diameter	Pipeline easement	Pipeline easement	Pipeline easement	Pipeline easement	Pipeline easement
Large diameter	Pipeline easement	Pipeline easement	Pipeline easement	Pipeline easement	10 metres
Large diameter with concrete slab[22]	Pipeline easement	Pipeline easement	Pipeline easement	Pipeline easement	Pipeline easement

Table 33 – Medium Pressure Gathering System, Minimum Distance to Satisfy Land use Criteria[23]

Low Pressure Gathering System	Minimum Buffer Distance (metres)				
	Industrial Buffer (50 x 10^{-6} /yr)	Active open space (10 x 10^{-6} /yr)	Business (5 x 10^{-6} /yr)	Residential development (1 x 10^{-6} /yr)	Sensitive development (0.1 x 10^{-6} /yr)
Small diameter	Pipeline easement	Pipeline easement	Pipeline easement	Pipeline easement	10 metres
Large diameter	Pipeline easement	Pipeline easement	Pipeline easement	Pipeline easement	60 metres
Large diameter with concrete slab[22]	Pipeline easement	Pipeline easement	Pipeline easement	Pipeline easement	10 metres

6.3.3 Injury Risk

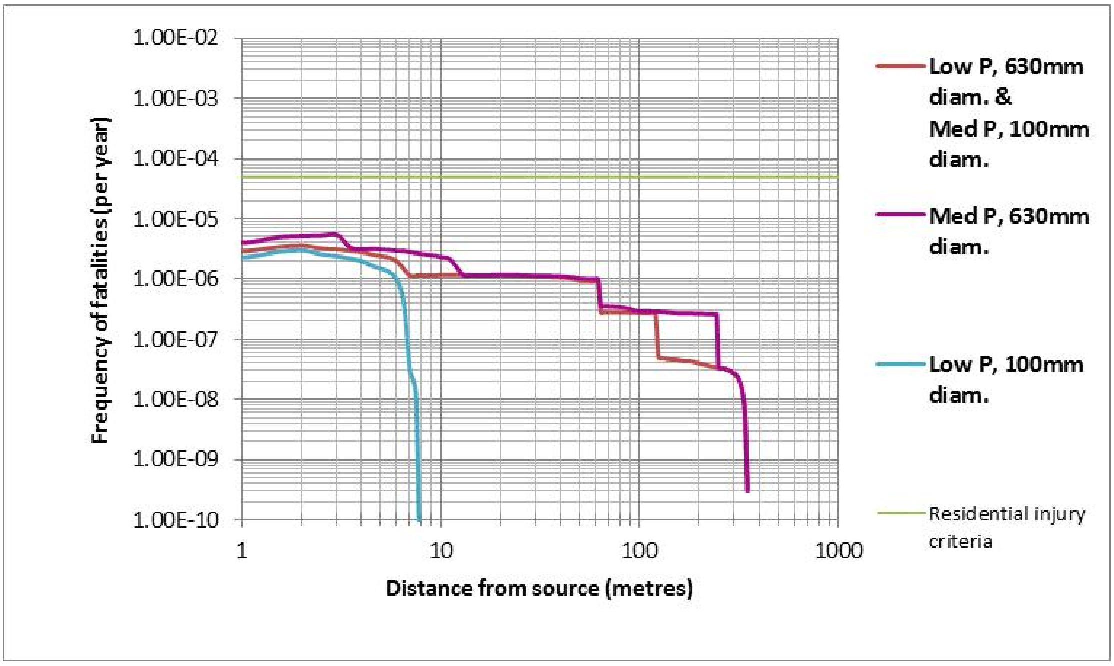
The injury risk for gathering lines is contained within the easement of the line. The injury risk criterion for the gathering line is met as shown in Figure 8. Please note that the results for a low pressure gathering line of large diameter (up to 630mm) and those for the medium pressure small diameter (up to 100mm) coincide.

[21] The minimum distances have conservatively been rounded up to the nearest 5, i.e. a calculated distance of 11, 12, 13, 14 or 15 metres would all be listed as of minimum distance to safety criteria of 15 metres.

[22] Putting a concrete slab on top of a below ground pipeline is assumed to reduce the likelihood of damage to the pipeline by third party interference by 90%. Seeing this type of damage is responsible for about 52% of the incidents the leak frequency of the below ground pipeline can be estimated.

[23] The minimum distances have conservatively been rounded up to the nearest 5, i.e. a calculated distance of 11, 12, 13, 14 or 15 metres would all be listed as of minimum distance to safety criteria of 15 metres.

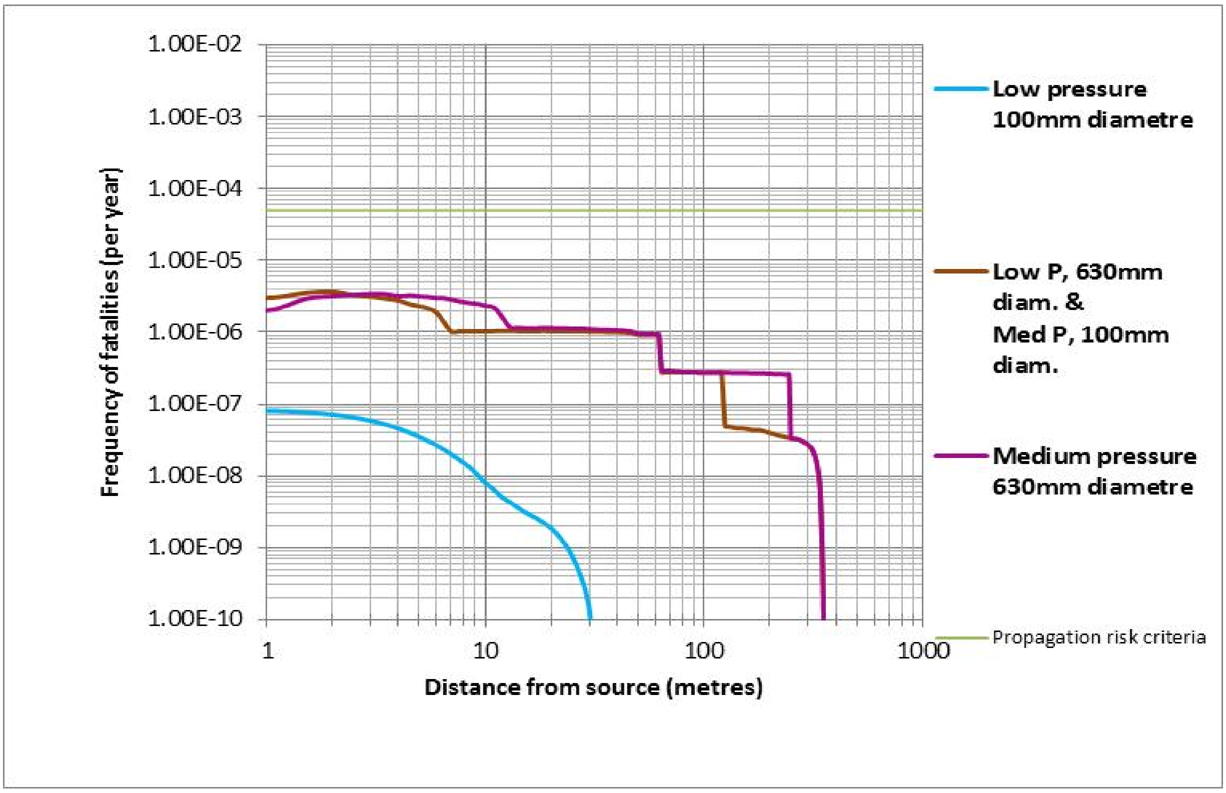
Figure 8 – Gathering Line Injury Risk



6.3.4 Propagation Risk

The propagation risk does not reach the risk criteria level and hence is not experienced at the gathering line. The propagation risk criterion for the gathering line is met as shown in Figure 9.

Figure 9 – Gathering Line Propagation Risk



6.4 FIELD COMPRESSION FACILITIES

6.4.1 Results of the Consequence Analysis

The quantitative risk associated with the FCFs relates to the handling and processing of gas. A summary listing for the significant incident scenarios is provided in the tables below. The scenarios do not take into account any isolation of the source of the gas and hence the release is *infinite.* In reality, the Field Compression Facilities will be monitored and emergency response will be able to be initiated. There will also be a number of automatic trips and isolations associated with the compressors, as discussed in Section 6.1.1 above.

The pressure at the inlet of the compressors will be relatively low compared with the pressure at the outlet of the compressors (which is classified as *medium*. The flow rate at the inlet of the compressors is therefore lower than for the outlet, as shown below.

6.4.2 Individual Risk of Fatality

The hazardous consequences of a number of the scenarios identified for the proposed development have the potential to affect the areas outside the immediate site or compound boundaries. However, due to the stringent risk management measures imposed, both legally through Codes and Standards, and through Arrow's Energy's internal systems, the likelihood of a major incident involving these facilities is very low.

Table 34 – Dispersion and Heat Radiation Modelling, Field Compression Facilities

Size of Release	Release rate (kg/sec)	Threat zone[24] for non burning gas	Threat zone for burning gas (jet fire) (m)		
		LFL[25] (metres)	22 kW/m^2	12 kW/m^2	4.7 kW/m^2
Inlet Pressure – Assume 150mm Diameter Inlet Pipe and 300kPa(g) pressure					
Rupture	6	8	18	23	38
10% Leak[26]	0.7	1.7	4	8	13
Outlet Pressure – Assume 150mm Outlet Diameter and 1,000kPa(g) pressure					
Rupture	15	15	28	35	58
10% Leak	2	4	8	13	22

[24] Refers to the maximum distance between Lower Flammable Limits of the CSG cloud.

[25] Maximum distances listed here are relevant for low wind stable conditions mainly experienced during night time. Risk assessment takes into account the probability of each wind weather condition as per Section 1.4.5.

[26] Hole size equivalent to 10% of the cross sectional area of the connecting pipeline

Table 35 – Heat Radiation from Flash Fire and Explosion Overpressure from Vapour Cloud Explosions, Field Compression Facility

Size of Release	Amount of Gas in Flammable Cloud[27] (kg)		Threat Zone, Flash Fire[28] (m)	Threat Zone, Vapour Cloud Explosion (m)	
	D4	F2		7 kPa	14 kPa
Inlet Pressure – 150mm Diameter					
Rupture	<10	<10	5	Not credible	Not credible
Major (10%)	<10	<10	2	Not credible	Not credible
Outlet Pressure – 150mm Diameter					
Rupture	736	813	90	94	72
Major (10%)	67	68	20	54	31

[27] As per consequence modelling, maximum amount of gas in cloud is limited through outflow rate and dispersion characteristics.

[28] The probability of fatality from exposure to a flash fire is based on 100% of people within a vapour cloud concentration greater than 0.5 times the lower flammable limit LFL.

A typical FCF includes two compressors, with both possibly in operation. The present risk assessment has investigated the individual risk of fatality associated with such a typical FCF layout with the results presented in Table 36 below.

Table 36 – Field Compression Facility With Two Compressor Units, Minimum Distance to Satisfy Land use Criteria

Wells	**Minimum Buffer Distance (metres)**				
	Industrial Buffer (50 x 10^{-6} /yr)	**Active open space (10 x 10^{-6} /yr)**	**Business (5 x 10^{-6} /yr)**	**Residential development (1 x 10^{-6} /yr)**	**Sensitive development (0.1 x 10^{-6} /yr)**
Outer edge of compressors at the Central Gas Processing Facility	Site boundary	20 metres from outer edge of compressors	30 metres from outer edge of compressors	35 metres from outer edge of compressors	55 metres from outer edge of compressors

A FCF may include up to six screw compressors or up to two reciprocal compressors (assuming one of each type of compressor on stand-by at any one time). The buffer distances between the FCF (comprising eight compressors) and a number of different land uses can be determined as per Table 37.

Table 37 – Field Compression Facility With Eight Compressor Units, Minimum Distance to Satisfy Land use Criteria

Wells	**Minimum Buffer Distance (metres)**				
	Industrial Buffer (50 x 10^{-6} /yr)	**Active open space (10 x 10^{-6} /yr)**	**Business (5 x 10^{-6} /yr)**	**Residential development (1 x 10^{-6} /yr)**	**Sensitive development (0.1 x 10^{-6} /yr)**
Outer edge of compressors at the Central Gas Processing Facility	Site boundary	20 metres from outer edge of compressors	30 metres from outer edge of compressors	50 metres from outer edge of compressors	100 metres from outer edge of compressors

The risk level from the FCF is relatively low due to the extensive ESD and venting capability around each compressor. Please note that no credit has been taken from any automatic emergency isolation at the entrance and exit of the natural gas pipeline to and from the site.

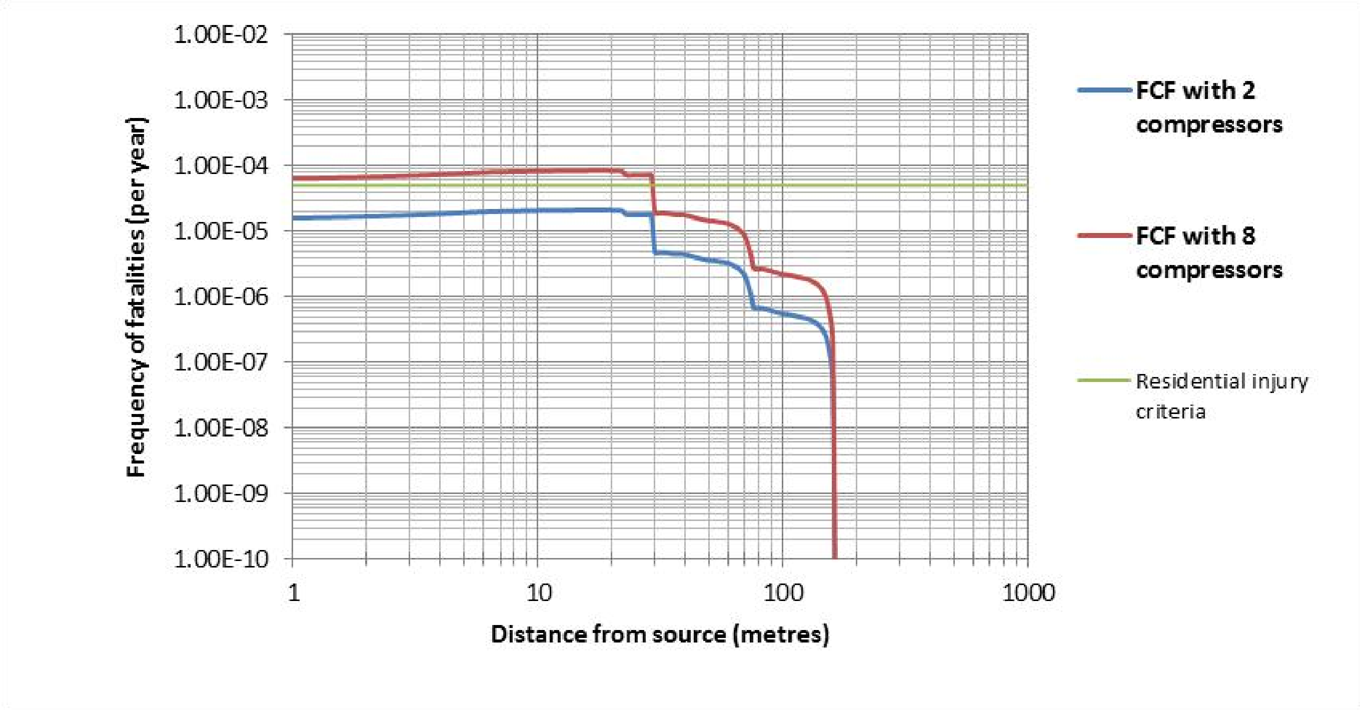
The level of risk associated with a FCF development which is considered *tolerable* for residential housing is three times lower than the risk of being killed by a falling object or being electrocuted in an non industrial environment, and is about ten times lower than the risk of being killed in an aeroplane accident in Australia (or 145 times lower than being killed while travelling in a car).

6.4.3 Injury Risk

The injury risk for a small (2 compressor) FCF is contained within the site, as shown in the figure below. The injury risk criterion for the FCFs is met.

The injury risk for the largest conceivable FCF (8 compressors) extend up to 30 metres from the outer edge of the compressors, as per the figure below.

Figure 10 – FCFs Injury Risk

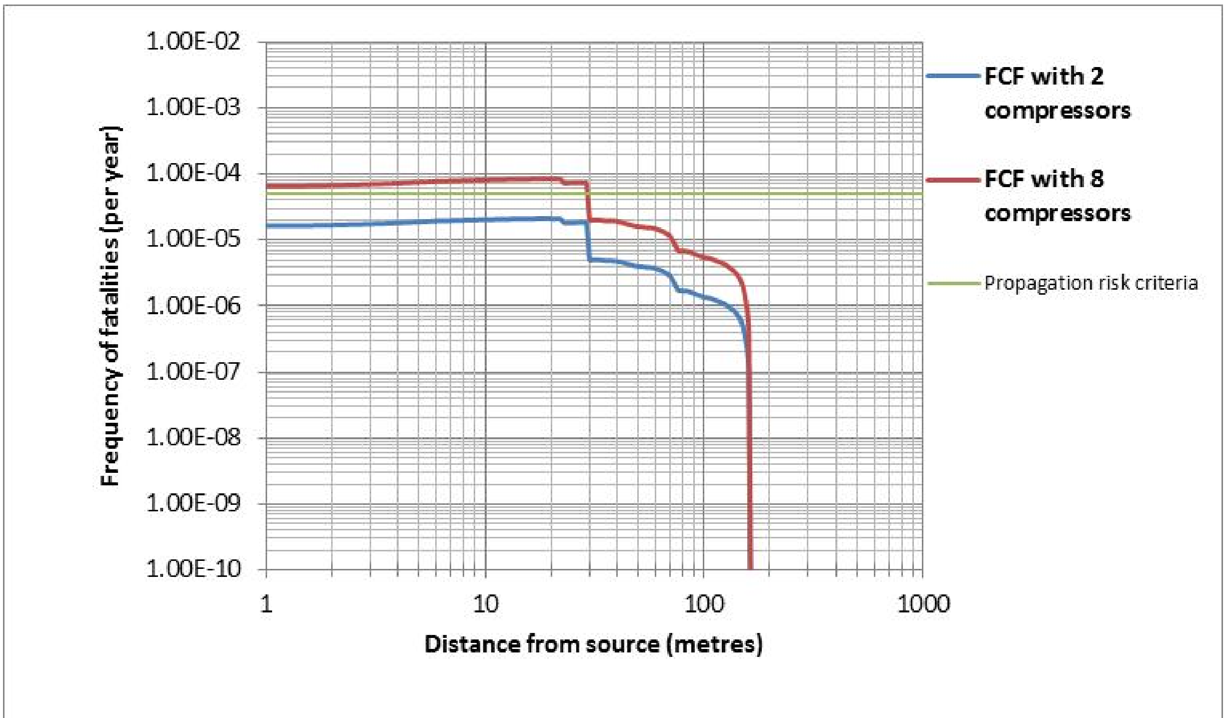


6.4.4 Propagation Risk

The propagation risk for a small (2 compressor) FCFs (FCFs) is contained within the site, as shown in the figure below. The propagation risk criterion for the FCFs is met for this small FCF.

The propagation risk for the largest conceivable FCF (8 compressors) extend up to 30 metres from the outer edge of the compressors, as per the figure below.

Figure 11 – FCF Propagation Risk



6.5 Central Gas Processing Facilities (Stand Alone or as Part of an Integrated Production Facility)

The main hazard and hence the quantitative assessment of risk associated with the CGPF (as a stand-alone facility or as part of an IPF) relates to the handling and processing of gas.

6.5.1 Results of the Consequence Analysis

The detailed results for each incident scenario included in this PHA are listed in Appendix 3. A summary listing for the significant incident scenarios is provided in the table below.

Table 38 – Dispersion and Heat Radiation Modelling, Central Gas Processing Facility

Size of Release	Release rate (kg/sec)	Maximum amount of gas released (kg)	Threat zone[29] for non burning gas (m)	Threat zone for burning gas (jet fire) (m)		
			LFL[30]	22 kW/m^2	12 kW/m^2	4.7 kW/m^2
CGPF – Upstream of Compressors, Assume 150mm diameter pipe and 1,000kPa(g)						
Rupture on site if ESD at battery limit initiates.	15	300[31]	15	28	35	58
Rupture on-site if the ESD at battery limit fails to isolate	15	Infinite[32]	15	28	35	58
Major (10%)	2	Infinite[32]	4	8	13	22
CGPF – At the Compressors or Downstream of Compressors, Assume 150mm diameter pipe and 9,800kPa(g)						
Rupture of pipe between compressors (isolation valves between the compressors close as designed)	136	200[33]	85	73	97	159
Rupture of pipe downstream of compressors (isolation valves between compressor and battery limit close as designed)	136	500[34]	85	73	97	159
Rupture of pipe downstream of compressors (the first ESD function fails but the second ESD function works)	136	3,000[35]	85	73	97	159
Major (10%)	22	3,000	20	19	23	38

[29] Refers to the maximum distance between Lower Flammable Limits of the CSG cloud.

[30] Maximum distances listed here are relevant for low wind stable conditions mainly experienced during night time. Risk assessment takes into account the probability of each wind weather condition as per Section 1.4.5.

[31] Approximate quantity of CSG between the inlet to the CGPF up to ESD valve at first compressor.

[32] Assumes that the gas wells continue to supply CSG to the FCF via the gathering line.

[33] Assumes a total of 200kg of CSG contained between ESD valves on each side of a compressor.

[34] Assumes a total of 500kg of CSG contained between the last ESD of the last compressor and the battery limit.

[35] This is the total approximate contents of CSG within one CGPF at any one time.

Table 39 – Flash Fire Heat Radiation and Vapour Cloud Explosions, Central Gas Processing Facility

Size of Release	Amount of Gas in Flammable Cloud[36] (kg)		Threat Zone, Flash Fire[37] (m)	Threat Zone, Vapour Cloud Explosion (m)	
	D4	F2		7 kPa	14 kPa
CGPF – Upstream of Compressors					
Rupture	<10	76	15	Not credible	Not credible
Major (10%)	<10	<10	4	Not credible	Not credible
CGPF – Downstream of Compressors					
Rupture (isolation valves between compressors close as designed)	178	180	85	35	20
Rupture (isolation valves between compressor and battery limit close as designed)	457	467	85	45	30
Rupture (first ESD function fails but second ESD function works)	850	985	85	70	45
Major (10%)	25	120	20	Not credible	Not credible

[36] As per consequence modelling, maximum amount of gas in cloud is limited through outflow rate and dispersion characteristics.

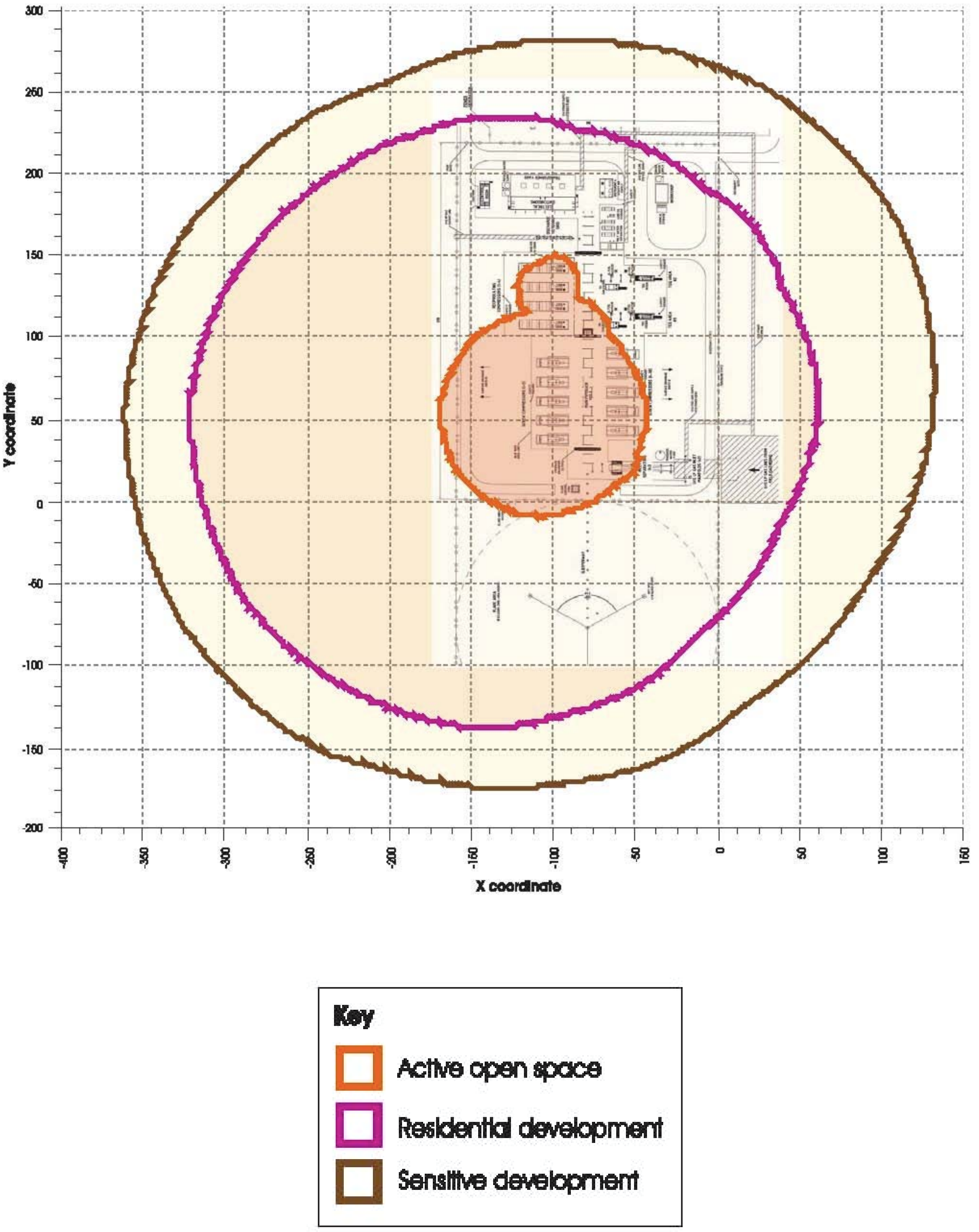
[37] The probability of fatality from exposure to a flash fire is based on 100% of people within a vapour cloud concentration greater than 0.5 times the lower flammable limit LFL.

6.5.2 Individual Risk of Fatality

The hazardous consequences of a number of the scenarios identified for the proposed development have the potential to affect the areas outside the immediate site or compound boundaries. However, due to the stringent risk management measures imposed, both legally through Codes and Standards, and through Arrow's internal systems, the likelihood of a major incident involving these facilities is very low.

The risk associated with the CGPF is best represented as *risk contours* overlaid on a site layout diagram, as shown in Figure 12 below. This site layout includes ten screw compressors and four reciprocal compressors (assuming one of each type of compressor on stand-by at any one time). The risk contours follow closely the compressors and are unlikely to extend significantly beyond the site boundary. These results do not change significantly with the number of gas compressors provided that the safeguards, as discussed in Section 4.4 above, are adhered to.

Figure 12 – CGPF Individual Risk Contours



The minimum separation distances between the CGPF and neighbouring land use are presented in below.

Table 40 – Central Gas Processing Facility, Minimum Distance to Satisfy Land use Criteria

CGPF	Minimum Buffer Distance (metres)				
	Industrial development (50×10^{-6} /yr)	**Active open space (10×10^{-6} /yr)**	**Business (5×10^{-6} /yr)**	**Residential development (1×10^{-6} /yr)**	**Sensitive development (0.1×10^{-6} /yr)**
Outer edge of compressors at the Central Gas Processing Facility	Site boundary	55 m from edge of compressors	75 m from outer edge of compressors	210 m from outer edge of compressors	290 m from outer edge of compressors

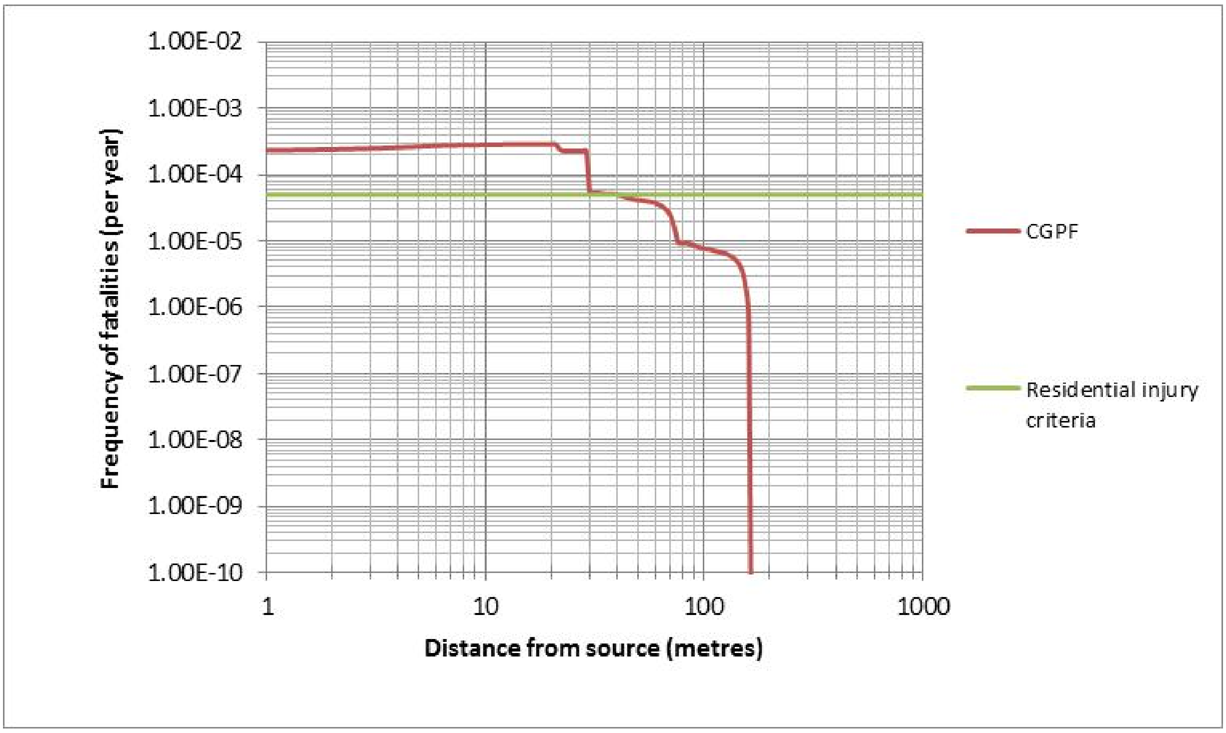
The risk level from the CGPF is relatively low due to the extensive ESD and venting capability around each compressor and at the entrance and exit of the natural gas pipeline to and from the site.

Please note that the level of risk associated with the development which is considered “tolerable” for residential housing is three times lower than the risk of being killed by a falling object or being electrocuted in an non industrial environment, and is about ten times lower than the risk of being killed in an aeroplane accident in Australia (or 145 times lower than being killed while travelling in a car).

6.5.3 Injury Risk

The injury risk extends 30 metres beyond the outer edge of the compressors on the CGPF (Figure 14).

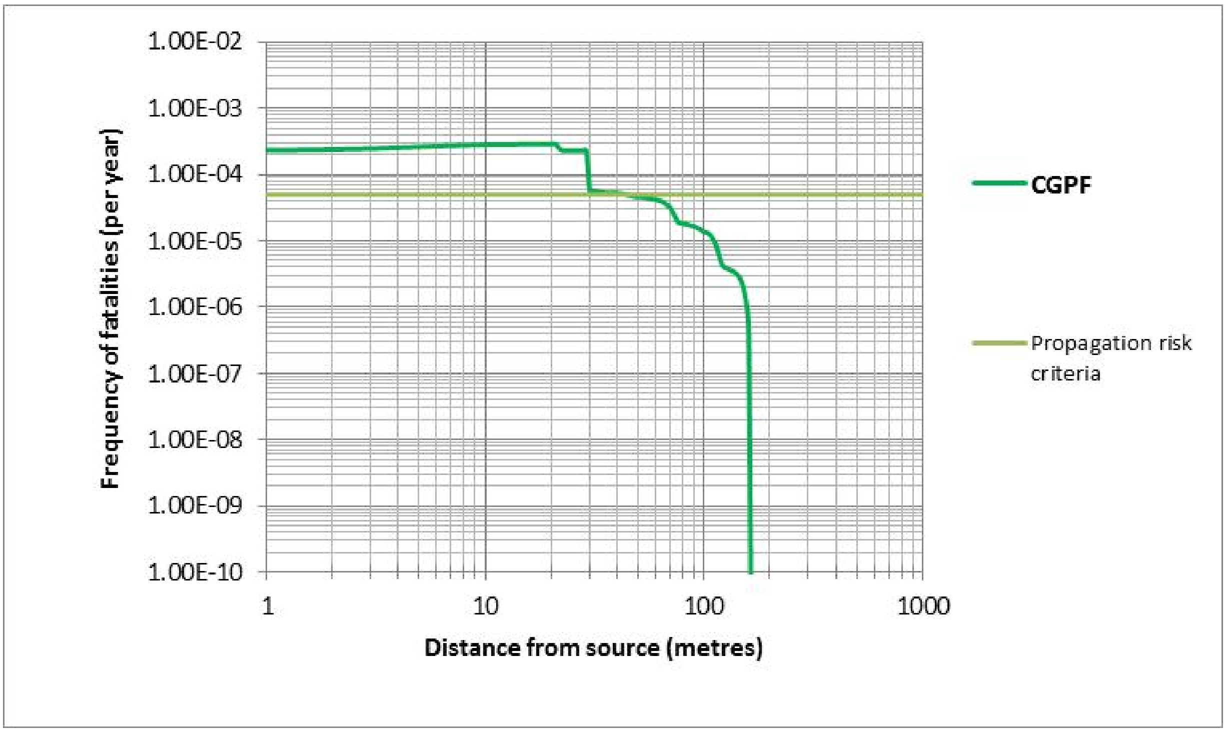
Figure 13 – CGPF Injury Risk



6.5.4 Propagation Risk

The propagation risk extends 30 metres beyond the outer edge of the compressors on the CGPF (Figure 15).

Figure 14 – CGPF Propagation Risk



6.5.5 Risk of Natural Gas Explosion in a Generator Enclosure

The compressors will not be located inside enclosures. However, if generators are required, these may need to be located inside enclosures, depending on the outcome of the noise and vibration impact assessment Should enclosures be required, there is a potential for accumulation of gas inside the enclosure and subsequent ignition resulting in a flash fire or even a vapour cloud explosion.

The risk of an explosion inside an enclosure is minimised through the use of a number of risk management measures, including Burner Management System within the gas burner and minimising the risk of accumulation of gas inside the generator enclosure through providing a natural draught through the enclosure in order to dissipate any small amount of gas which may be emitted from process equipment. Further, a number of gas detectors are also fitted inside the enclosures which would initiate start-up of a fan to further increase the dissipation of gases in case of detection of gas. If the gas concentration exceeds a set value (generally about 20% of the Lower Flammable Limit for methane) an emergency response would be initiated by quickly depressuring via venting the gas and by limiting air ingress into the enclosure (the fan would cut out, the louvers would shut, the compressor would shut down and the gas contained in process piping would be vented).

The function of the enclosure is to provide weather protection and sound isolation, and consists of light metal sheeting and sound isolation fibre. The enclosures are not designed to contain an explosion. The metal sheeting is assumed to simply blow out in an overpressure situation (it could be the louvers that are the weakest link), and the PHA has assumed that in case of an explosion, the effects would be as for a (largely) non confined situation.

The likelihood of a confined explosion inside the compressor building was estimated taking into account that the following risk management features:

- Minimising lengths of gas piping and connections inside the enclosure;
- Reliable ventilation fan system;
- Gas detection linked to automatic emergency shut down and depressurization (venting) system;
- Use of light construction enclosure with blow out-panel (or louvers);
- Separation distances to nearby pressure piping and equipment.

The frequency of explosion inside the generator building can be estimated with the following formula:

Explosion frequency = (Gas release frequency within building) x (Ventilation fan failure probability) x (Gas detection and emergency shutdown failure probability) x (Ignition probability of accumulated gas) x (Explosion if ignition probability).

With the following assumptions:

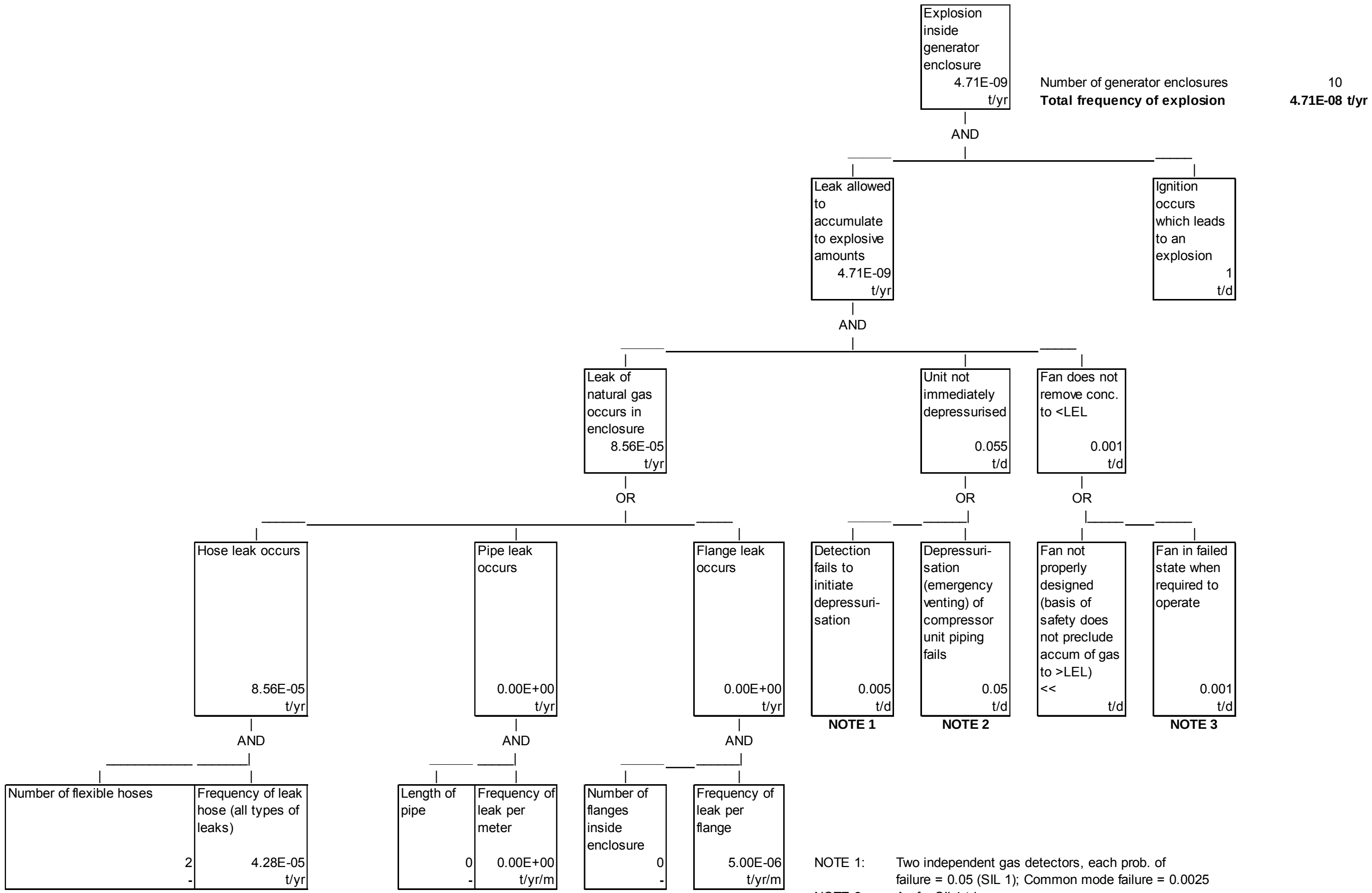
- Gas leak frequency = 2.5 x 10^{-5} t/yr per generator (assuming equipment failure frequencies as per Appendix 4 and zero flanges with no natural gas piping inside enclosure apart from the 2 x 0.5 meters of flexible lines).
- Probability that the unit fails to immediately depressurised in case of leak = 0.055 (taken as the failure of two independent leak detection systems of SIL1 (including common mode failure, i.e. 0.05 x 0.05 + 0.0025) to initiate the depressurization or the failure to activate the emergency vent valve (taken as SIL 1 = 0.05).
- Ventilation fan failure probability, allowing accumulation of gas = 0.01 (based on industry experience with similar fans and on the fact that if the vent is operating 100% of the time when the unit is pressurized and that a failed vent will be alarmed at the Control Centre allowing for initiating of emergency response).
- Ignition probability of accumulated gas = 1. Even though all equipment and instrumented protective equipment used in the enclosure is designed for the hazardous zone requirements, a generator could have hot surfaces above the auto ignition temperature of the fluids used even in normal circumstances (operation under fault conditions may increase surface temperatures).
- Explosion if ignition probability = 1 (i.e. assuming that all ignitions of flammable gases inside the housing would lead to an explosion. This is conservative).

Calculations show:

> Explosion frequency = 1.2 x 10^{-9} per year per generator enclosure. With ten enclosures containing operational generators the frequency of an explosion at the generator enclosure is 1.2 x 10^{-8} per year.

This frequency is very low. The logic of the calculation of the incident frequency is shown in the fault tree in the figure below.

Figure 15 – Fault Tree of Generator Enclosure Explosion Incident



NOTE 1: Two independent gas detectors, each prob. of failure = 0.05 (SIL 1); Common mode failure = 0.0025

NOTE 2: As for SIL1 trip

NOTE3: As per industry experience with similar fans. Also, fan operated 100% when unit is on and 0% when unit is off. If fan fails, alarm to Ctrl Room who will inform out technician.

6.6 HIGH PRESSURE GAS PIPELINE

The risk associated with the high pressure gas pipelines is the same as for the Arrow Energy Surat Pipeline which was assessed according to the AS2885.1 (Ref 7) technique for risk assessment in the Environmental Impact Statement in Ref 2.

7 RISK MANAGEMENT

The safe construction, operation and decommissioning of any potentially hazardous facility depends on the rigorous application of many risk management controls. The present hazard and risk assessment has been developed based on the understanding that such controls are in place or will be developed for the Arrow Surat Gas Project. These controls have been listed against each risk throughout this PHA and, for ease of reference, have been listed below.

7.1 GENERAL OCCUPATIONAL HEALTH AND SAFETY REQUIREMENTS FOR ALL PHASES OF THE PROJECT

- Arrow will prepare safety management plan(s) (SMPs) for the construction, operation and decommissioning of the infrastructure that form part of the present development.
- Safety during construction (and decommissioning) of all high pressure gas pipelines will follow the intent of the Australian Pipeline Industry Association (APIA) for Construction Health and Safety Guidelines, including the preparation of a Construction Health and Safety Plan (*Construction H&S Plan*).
- Arrow's Health, Safety and Environment Management System (HSEMS) Manual will apply for each plant and activity that forms part of this development.
- The Safety, Health and Environmental Policy will be applied and, if necessary, reviewed and a Safety Organisation (including requirements for management, supervision, communications, committees etc.) will be established.
- Formal safety study processes will be applied during design of new and modified facilities, including the use of hazard and risk assessment processes. These formal safety studies will be based on well recognised methodologies, e.g. Hazard and Operability (HAZOP) studies and AS2885 risk assessment (*Safety Management Studies*).
- Incident management systems will be established for the facilities and operations, including formal systems for reporting, investigation and communications of lessons learned to prevent recurrence by identifying and managing immediate and root causes.
- Operating procedures will be established for the management of hazards identified in this PHA. These procedures will detail responsibilities and safety precautions required to safely manage the plants and processes forming part of this development.
- Where operating procedures are not applicable, for example for non-routine operations and maintenance activities, Permit to Work (PTW) systems will be established. The PTW system will include a rigorous JSEA process.
- Management of Change (MOC) processes will be established and applied, including protocols for communication of changes to appropriate levels of management and "Control of Defeat", especially on operating equipment and facilities.
- Safety training programs will be set up for personnel and contractors, including induction training of new starters. Supervision requirements will be established, including supervision during drilling and construction operations.
- Emergency response plans will be developed for each type of facility. Equipment, training and other resources will be identified, documented and maintained for all foreseeable emergency and crisis situations (including escapes, blowouts, gas fire, bush fire, critical

equipment failure, trapped/missing people, flooding, cyclones, power failure, security incidents and threats and transport incidents). The plans will include safe evacuation procedures, communication (internal and to emergency services including the Petroleum and Gas Inspectorate), accounting for personnel and visitors, roles and responsibilities and requirements for training).

- Fire Plans will be prepared for FCFs, CGPFs and IPFs.
- All elements of the safety management system, including of emergency plans, will be reviewed regularly and whenever significant change is made.
- Internal and external (independent) hazard audit program(s) will be established, covering all major aspects of risk management listed above. Results from audit will be communicated to management. Timetables for rectification of deficiencies will be part of the corrective action process, with specific persons nominated responsible. Adherence to timetables will be periodically reviewed by management.

7.2 Risk Controls Specific for Construction

7.2.1 General

- Arrow safety management system would be in place during construction activities.

- Pre-job safety meetings will be conducted during construction activities.
- Pressure testing and inspection of equipment and pipelines will be carried out in accordance with established procedures and relevant government regulations.
- Work at heights and under suspended load to be managed, including tag lines to be used on all suspended loads, inspection / register of harnesses and height safety equipment and anchor points. Personal fall arrest equipment and wrist straps and lanyards to secure tools to be used at heights.
- Whip check or safety chain will be used and tie downs (or equivalent) on all high pressure lines and pressurised air hoses.
- Preventative Maintenance (PM) programs will be established for all equipment, including for electrical equipment (correct grounding of rig electrical circuit), with specific focus on management of pressure vessels, pipelines and Pressure Safety Valves (PSVs).
- Hazardous Zones will be defined and enforced. Fences will be provided for all above ground facilities, with the Hazardous Zone contained inside the fence line.
- Blow-out of pipes and equipment, to clean from construction debris, will be performed using well established procedures and under strict controls, including those detailed in risk assessments.
- Fire risks during access to facilities and construction locations will be managed through track selection (to avoid sensitive environmental areas) and track maintenance and use of designated track only.
- Fire breaks will be established and fuel (timber, grass, etc.) will be managed around above ground facilities.

- Fire safety requirements will be investigated, including establishing where fire extinguishers and other fire fighting equipment are required. Fire fighting equipment will be inspected and serviced in accordance with established frequencies.
- Protocols will be established for the control of construction activities during extreme fire danger periods.
- Risks of injury during transport to and from construction locations will be managed through a number of transport related safety programs including driver training, travel management plans, PM programs of vehicles, driver assessment in Safe Vehicle SOPs for Remote Locations, clearly defined Transport Management policy and procedures, detailed route planning including nominated rest stops, heat stress management procedures, and 1 of the 12 lifesaving rules.
- Chemicals stored and used during construction will be managed, including training of relevant staff and contractors in chemicals handling; design and maintenance of storage and handling facilities; use and maintenance of appropriate static grounding and portable earthing straps; MSDSs made available; dangerous goods storage and transport legal requirements rigorously followed; PPEs readily available and in use; spill kits available.
- General safety risks managed through barricading of trenches and ditches, use of PPE, high visibility vests worn, speed limits, and application of training of staff and contractors.
- Application of State Planning Policy 1/03, Mitigating the Adverse Impact of Flood, Bush Fire and Landslide.

7.2.2 Gas Wells

- Blow Out Preventors (BOPs) will be installed at all times during flow testing. BOP Test procedures will be in place for the Drilling Contractor and well control and BOP procedures will be established.
- Drilling program will be established and enforced.
- All equipment for drilling will be certified (where applicable).
- Front-end loader operators will be licensed.
- Rig move plan load out plan and approved rig-up procedures, and rig layout diagram will be supplied as part of the Completion Plan.

7.2.3 Pipeline Construction

- Construction Health and Safety Plan (Construction H&S Plan) will be established, including facility/project description, formal safety assessment and establishment of safety management systems.
- A Risk Control Action Plan will be prepared as part of the Safety Assessment process.
- A system to monitor the effectiveness of controls and implementation of the Risk Control Action Plan to continuously improve health and safety performance on the project will be implemented.
- Determining maximum distance between isolation valves (manual) installed at the pipelines.

7.2.4 FCFs, CGPF and IPF

- Fire safety equipment will be commissioned in the very early phase of the construction period.
- Smoke and/or fire alarms will be fitted,
- Hazardous Zones will be defined and enforced.
- Blow-out of pipes to clean from construction debris will be performed using well established procedures and under strict controls, including those detailed in risk assessments.
- Purging procedures, to free equipment from oxygen prior to introducing flammable gas, will be established and enforced.

7.3 Risk Controls Specific For Operational Phase

7.3.1 General

- Preventative Maintenance (PM) programs will be established for all equipment, including for electrical equipment (correct grounding of rig electrical circuit).
- Hazardous Zones will be defined and enforced. Fences will be maintained for all above ground facilities, with the Hazardous Zone contained inside the fence line.
- Purging of pipes and equipment, after shut down, will be performed using well established procedures and under strict controls, including those detailed in risk assessments.
- Maintenance of fire breaks will be established and fuel (timber, grass, etc.) will be managed around above ground facilities.
- Fire fighting equipment will be inspected and serviced in accordance with established frequencies.
- Protocols will be established for the control of operational activities (for example flaring and possible requirements to shut down facilities) during extreme fire danger periods.
- Chemicals stored and used during operation will be managed, including training of relevant staff and contractors in chemicals handling; maintenance of storage and handling facilities in accordance with well-established protocols; MSDSs available; dangerous goods storage and transport legal requirements rigorously maintained; PPEs readily available and in use; spill kits available. Portable bunds used during transferring oil or diesel.
- Non-static clothing worn.
- Application of State Planning Policy 1/03, Mitigating the Adverse Impact of Flood, Bush Fire and Landslide.

7.3.2 Gas Well Operation

- All pipes and vessels will be designed to cope with maximum pressure.
- Pressure transmitters will be installed, with High and Low pressure alarms which will be monitored 24 hour/7 days with possible call outs of technicians to rectify issues.

- Manual isolation valves at well and skid edge.
- Remote control isolation on gas and water lines.
- Risks of injury during transport to and from well sites and along pipelines (e.g. for inspections and maintenance) will be managed through a number of transport related safety programs including driver training, travel management plans, PM programs of vehicles, driver assessment in Safe Vehicle procedures for Remote Locations, clearly defined Transport Management policy and procedures, detailed route planning including nominated rest stops, heat stress management procedures. Further, this forms part of Arrow's *lifesaving rules,* which attract particular attention and control through a number of management systems.
- Design of equipment to withstand considerable heat load, e.g. through use of heat resistant (fire safe) isolation valves on FCFs and CGPFs.
- Fire risks during access to facilities and construction locations will be managed through track selection (to avoid sensitive environmental areas) and track maintenance and use of designated track only.
- Establishment and enforcement of *lone worker* protocols and communication.
- Establishment and enforcement of protocols when working during times of bush fire.
- Procedures and maintenance/workover procedures including requirements for purging.
- Risk control during workover operation, refer to section above.
- Pumps, where fitted, have an automatic pump shutdown or other safety device to prevent leak in case of pumping against a blockage.

7.3.3 Pipeline Operation

- Risks of injury during transport to and from well sites and along pipelines (e.g. for inspections and maintenance) will be managed through a number of transport related safety programs including driver training, travel management plans, PM programs of vehicles, driver assessment in Safe Vehicle procedures for Remote Locations, clearly defined Transport Management policy and procedures, detailed route planning including nominated rest stops, heat stress management procedures, and 1 of the 12 lifesaving rules.
- Regular patrol and inspections of pipeline easements, including of status of signposting, depth of cover to be maintained (control against erosion) and of fire breaks.
- Landowner liaison.
- Registration of Arrow pipelines and below-ground electrical services with "dial before you dig"

7.3.4 FCFs, CGPF and IPF

- Minimising of enclosed space where flammable gas may accumulate.
- Automated ESD system including remote monitoring and control.
- Flow and pressure instrumentation to transmit upset condition and plant shutdown valves status.

- Fire/gas detection system on either side of the compressors to shutdown compressors (e.g. through use of low suction pressure trip on gas compressors or other practicable means of initiation).
- Security controls (fencing, locked gates).
- Standards for oxygen purging to be set up (as new lines and wells are frequently being commissioned, oxygen may be an issue).
- Exclusion zone around flare based on radiation contour calculation as per API standard (including fire break, separation distances to buildings and any temporary huts, personnel access).
- Installation of lightning mast and earthing grid to minimise risk of lightning strike at FCFs, CGPFs and IPFs.
- Control of flooding risk through site location, drainage etc., particularly for FCFs, CGPFs and IPFs.
- Machine guarding on all rotating equipment in accordance with Australian Standards.
- Appropriate drainage of wastes through design and operation. Concrete floor with floor drainage system for small spills within building.
- Bunded storage area (in accordance with relevant standards).
- Automated chemical dosage system for water treatment at IPFs.
- No toxic gases used for water treatment (only liquids - a liquid loss of containment is easier to manage).
- Operator controlled unloading of chemicals on each FCF, CGPF and IPF.
- ESD buttons available on each FCF, CGPF and IPF site.

Specific for dam control:

- Fencing and signage will be put in place to ward off unlawful access.
- Line banks of dam with textured HDPE (ridged material).
- Escape ropes will be provided at strategic locations within the dam.
- Ladders will be provided at strategic locations within the dam.
- Overflow and operational controls of dams established and monitored.
- Approved dams (by DERM).
- Mandatory reporting levels.
- Freeboard requirements followed and managed through monitoring and regular inspection.
- External monitoring of bores.

7.4 Risk Control Specific for Decommissioning

- All plant and equipment in flammable gas use would be depressurised and degassed prior to decommissioning.

- Depressurising and purging activities would be carried out by suitably trained and supervised staff or contractors using procedures and formal systems in place to manage hazards and risks, including Job safety analysis and Permit To Work.
- Arrow safety management system would be in place during decommissioning activities.
- Also refer to risk controls during construction activities which also apply during decommissioning activities.

8 CONCLUSION

8.1 ESTABLISHMENT OF CONSTRAINTS

As discussed in Section 1.3, *Statement of Environmental Values,* provided that adequate buffer zones around the proposed petroleum exploration and operations activities are established, it is possible for these activities to co-locate with people and property.

At this early stage of the project there is an inherent uncertainty associated with the location of any of the infrastructure, which form part of the present development project. Constraints are therefore required to be developed for a range of different perspectives – in the case of this PHA, the constraints have been developed in terms of hazards and risks associated with the infrastructure.

These constraints describe the minimum buffer zones, around the activities, which form part of this development, and existing and future land uses in that area, as presented in Table 41 below.

For well heads, the calculated buffer zone is significantly smaller than that proposed by Arrow, through their internal management practices. In this case, the internal Arrow buffer zone is presented in Table E1.

Note that this table does not include the high pressure gas pipelines pipeline. Constraints as to the location of the high pressure gas pipelines are established on a case-by-case basis following the requirements in AS2885.1 (Ref 7) and as determined in the Environmental Impact Statement for the Arrow Surat Pipeline in Ref 2.

The hazard and risk framework has been developed based on the extent and the degree of hazardous impact that each activity may have on people safety and property.

The hazard and risk framework represents the minimum distance from the proposed Arrow activity to neighbouring sensitive receptors and are established on the basis of tolerable risk levels in use in Queensland.

There are other criteria (such as noise or nuisance), which have been established through other specialist reports and reported in the EIS, which may increase these distances beyond what is listed in the table below.

Further, Arrow Energy may also increase these buffer distances to satisfy their internal requirement for hazard and risk management of the facilities under their control.

Table 41 – Hazard and Risk Framework Approach

Constraint	Applicable Framework	Project Activity		
		Production and operation of wells	Gathering lines	CGPF, IPFs and FCFs
No go	**National parks:** No IPFs (including CGPFs, compression facilities, water treatment facilities, dams or power generation facilities) within one km of Wondal Range National Park and Bendidee National Park. No production wells within 100 m of the Wondul Range National Park and Bendidee National Park. No high pressure gas pipelines or gathering lines within 100 m of the Wondul Range National Park and Bendidee National Park.	NO	NO	NO
No go	**Within towns and townships:** No activity is permitted. Design controls will be applied to ensure all staff and contractors comply with the constraint. A number of towns and built up areas fall within Arrow Energy's petroleum tenures, either in whole or in part. This includes the towns of: Columboola, Chinchilla, Brigalow, Warra, Macalister, Dalby, Cecil Plains and Millmerran.	NO	NO	NO

Constraint	Applicable Framework	Project Activity		
		Production and operation of wells	**Gathering lines**	**CGPF, IPFs and FCFs**
No go	***Sensitive Development***, including schools, hospitals, prisons, day cares, aged care facilities: Site-specific assessment is required with respect to any existing or proposed sensitive development in the area. This should include formal and documented discussions with landholders and with Local Councils. Standard operating procedures in conjunction with site-specific controls will be developed to minimise impact to acceptable levels. Emergency conditions should be considered and mitigated. • No gas wells within the Arrow minimum 200 m buffer distance (distance measured from the well head to the boundary of the sensitive development). • No FCFs within the Arrow minimum 200 m buffer distance (distance measured from the outer edge of the compressors to the boundary of the sensitive development). • No CGPF or IPFs within 290 m of sensitive development (distance measured from the outer edge of the compressors the boundary of the sensitive development). • No large diameter (greater than 100 mm) low pressure gas gathering lines within 10 m of sensitive development (distance measured from the centreline of the pipeline to the boundary of the sensitive development). Low pressure gas gathering lines with internal diameter equal to or less than 100 mm can be placed adjacent to sensitive development provided the easement is maintained. • No large diameter (greater than 100 mm) medium pressure gas gathering lines within 60 m of sensitive development (distance measured from the centreline of the pipeline to the boundary of the sensitive development). Medium pressure gas gathering lines with internal diameter equal to or less than 100 mm or with large diameter and equipped with a concrete slab on top can be placed adjacent to sensitive development provided the easement is maintained. • High pressure gas pipelines: Design requirements for T2 *High Density Residential* will apply for pipelines installed within the measurement length of 864 metres of a sensitive development.	NO	NO	NO

Constraint	Applicable Framework	Project Activity		
		Production and operation of wells	Gathering lines	CGPF, IPFs and FCFs
Moderate	***Near residential development*** Site-specific assessment is required with respect to any existing or proposed residential development in the area. This should include formal and documented discussions with landholders and with Local Councils. Standard operating procedures in conjunction with site-specific controls will be developed to minimise impact to acceptable levels. Emergency conditions should be considered and mitigated. • No gas wells within the Arrow minimum 200 m buffer distance (distance measured from the well head to the home or resident). • No FCFs within the Arrow minimum 200 m buffer distance (distance measured from the well head to the home or resident). • CGPF and IPFs may be developed in areas where the buffer zone from the outer edge of the compressor to the boundary of residential development exceeds 210 m. • Gathering lines (low and medium pressure) may be established in areas where the buffer zone from the centre of the gathering line to the boundary of residential development exceeds 8 m, provided the easement is maintained and provided the location, threat and risk analysis provide acceptable risk levels. • High pressure gas pipelines: The design requirements for T1 *Residential* or T2 *High Density Residential* will apply for pipelines installed within the measurement length of 864 metres of a residential development.	YES	YES	YES

<table>
<tr><th rowspan="2">Constraint</th><th rowspan="2">Applicable Framework</th><th colspan="3">Project Activity</th></tr>
<tr><th>Production and operation of wells</th><th>Gathering lines</th><th>CGPF, IPFs and FCFs</th></tr>
<tr><td>Moderate</td><td>Development next to active open space, business or industry: Site-specific assessment is required with respect to any existing or proposed active open space, business or industry development in the area, including formal and documented discussions with landholders and with Local Councils. Standard operating procedures in conjunction with site-specific controls will be developed to minimise impact to acceptable levels. Emergency conditions to be considered and mitigated. From a hazard and risk point of view:
Gas wells may be developed in areas where the buffer zone from the wellhead to the boundary of business/open space exceeds 30 m and to a neighbouring business or industrial development exceeds 10 m.
Gathering lines (low or medium pressure) may be established in areas zoned as active open space, business or industry provided the easement is maintained and provided the location, threat and risk analysis provide acceptably risk levels.
FCFs may be developed in areas where the buffer space exceeds 30 m to neighbouring business and active open space. Neighbouring industrial facilities may be established at the site boundary of the FCF.
CGPFs and IPFs may be developed in areas where the buffer space exceeds 80 m to neighbouring business. Neighbouring industrial facilities and active open space may be established at the site boundary of the CGPF or the IPF.
High pressure gas pipelines: The design requirements for (I) Industrial or (HI) Heavy Industrial will apply for pipelines installed within the measurement length of 864 metres of an industrial development. Special design requirements for pipelines installed within land defined as a Common Infrastructure Corridor (CIC), or which because of its function results in multiple (more than one) infrastructure development within a common easement or reserve, or in easements which are in close proximity.</td><td>YES</td><td>YES</td><td>YES</td></tr>
</table>

8.2 CUMULATIVE RISK DURING DESIGN AND INSTALLATION

Fourteen risk scenarios were identified for the design and installation phase, as follows:

Risk scenario	Facility	Level of Risk
Fire risk due to ignition of flammable or combustible material	Wells	Low
	FCFs CGPFs IPFs	Medium
Fire incident involving gas released during blowdown which catches fire and causes injury or destruction of property;	Wells	Low
	FCFs CGPFs IPFs	
Operator injury and equipment damage due to pressure burst;	Wells FCFs	Low
Injury due to loss of containment of liquids pollutant materials	FCFs CGPFs IPFs	Low
Injury to workers during construction	Wells FCFs CGPFs IPFs	Medium
Access track causes environmental impact or bush fire during construction, use and maintenance.	Wells Gathering System	Medium
Threat to people, plant and equipment due to external event such as bush fire.	Wells Gathering System FCFs CGPFs IPFs	Medium
Injury to driver due to transportation risks	Wells	Medium
Injury due to loss of containment of liquid hazardous materials (diesel, hydraulic oil, bentonite, drilling foam) or saline water;	Wells	Low
Injury due to electrocution at faulty electrical equipment;	Wells Gathering system FCFs CGPFs IPFs	Low
Confined space hazards to operators and contractors	Wells Gathering system	Low
General safety hazards to people from use of heavy machinery, vehicles, earth-moving	Gathering system	Medium
Safety risk from holes, ditches, uneven terrain, heavy vehicles	Gathering system	Medium
Flammable gas co-mingles with water source	Wells	Medium

The gas wells and the gathering system are likely to be constructed on locations containing numerous safety hazards such as ditches, holes, uneven terrain and sharp objects. The land is also likely to contain venomous snakes and spiders. Installation of these developments will also involve heavy machinery, rotating equipment, handling of electrical sources. Such risks are managed using Arrow safety, health and environmental procedures and protocols.

Risks to workers during initial commissioning of the dams from possible faults, not readily apparent before the dam is being filled, will be assessed and managed prior to construction.

Risks to workers during initial commissioning of wells, gathering system, FCFs, CGPFs, IPFs and high pressure gas pipelines from potential ignition of flammable gas will be assessed and managed prior to introduction of a source if ignition. The absence of fraccing means that geological structures are highly to be affected (though they will be intersected) during well drilling.

8.3 CUMULATIVE RISK DURING OPERATION AND MAINTENANCE

Sixteen risk scenarios were identified for the operations and maintenance phase, as follows:

Risk scenario	Facility	Level of Risk
Fire risk due to ignition of flammable or combustible material	Wells Gathering system FCFs CGPFs IPFs	Medium
Fire at the electrical generator	Wells	Very Low
Operator injury and equipment damage due to pressure burst;	Wells FCFs	Medium
Ingress of air into process piping	Wells Gathering system FCFs CGPFs IPFs	Low
Fire exerted from flaring activity	FCFs CGPFs IPFs	Low
Injury due to loss of containment of liquids pollutant materials	Gathering system FCFs CGPFs IPFs	Medium
Injury to workers during use of heavy machinery, equipment, construction	Wells FCFs CGPFs IPFs	Medium
Access track causes environmental impact or bush fire during construction, use and maintenance.	Wells Gathering System	Medium
Threat to people, plant and equipment due to external event such as bush fire.	Wells Gathering System FCFs CGPFs IPFs	Low

Risk scenario	Facility	Level of Risk
Injury to driver due to transportation risks	Wells	Medium
Injury due to loss of containment of liquid pollutant materials	Wells FCFs CGPFs IPFs	Medium
Injury due to electrocution at faulty electrical equipment or power lines	Wells Gathering system FCFs CGPFs IPFs	Low
Confined space hazards to operators and contractors	Wells Gathering system	Low
Safety risk from holes, ditches, uneven terrain, heavy vehicles.	Wells Gathering system	Low
Injury to personnel from damaged rotating machinery	FCFs CGPFs IPFs	Low

Incidents during production and handling of gas have the potential to affect areas outside of the immediate compound or site. The gas can ignite in the presence of oxygen (air) and an ignition source. If ignited, the gas can either burn as a fire or explode (in the case of a confined release), generating overpressure effects. Fires pose the obvious hazard of intense heat, open flame and smoke inhalation. Fires may also cause damage to equipment and on or off site facilities.

The risk associated with the production and handling of the gas at the proposed development is as low as reasonably practicable (ALARP) provided the hazard and risk framework approach for the proposed development is maintained, as discussed above.

People who may be exposed to hazards associated with the production, transport and treatment of the gas comprise personnel, contractors and visitors.

The types of hazards, which require consideration for people inspecting, visiting, maintaining and working with these developments (workers and visitors) during operation, maintenance and workover operations include:

- Flammable hazards from the gas and, to a much lesser degree, from other combustible materials held on-site (diesel, TEG);
- Pressure hazards from the gas, compressors and generators;
- Mechanical hazards from rotating machinery and moving vehicles;
- Exposure to harmful materials such as saline water, diesel or oil (and, in the case of the CGPF, to largely corrosive water treatment chemicals);
- Electrocution hazards (including power lines, generators and electrical equipment);
- Hazards associated with large quantities of water held in dam, including the risk of drowning and the risk of dam wall collapse.

The measures required to minimise these hazards will be incorporated into the Arrow Safety Management System, site operating procedures and contingency plan.

8.4 OTHER RISKS

8.4.1 Bush Fire Risk Management

Arrow will implement risk management procedures to Australian Standards and individual Site Management Plans (SMP). Full cooperation with the various regulatory authorities and local services such as the Rural Fire Service (RFS) will be developed and maintained. Each site will form part of Emergency Response Procedures (ERP), as part of the requirements in the Schedule of Onshore Petroleum Exploration and Production Safety Requirements (clause 210 of the Schedule), Ref 29. These safety measures will be developed using proper risk management protocols and procedures in full consultation with all stakeholders including the RFS.

Bush fire hazard is commonly classified in three levels, *low*, *medium* or *high* hazard. This rating is achieved based on a number of criteria including historical fire events, vegetation and gradient of the land.

As determined in the Planning Assessment report (Ref 30), which forms part of the EIS, the hazard rating for the Surat Gas Project development area is a mixture of *medium* and *low* hazard with predominantly *low* hazard areas. The main areas of concern are located south of the Wandoan throughout the entire region of Guluguba as well as the northern section of Miles, which again is denominated as a medium bush fire hazard area. From then on the southern section of Wambo down through to the western section of Milmerran is designated as medium bush fire area.

Low bush fire hazard areas are characterised by predominant crazing and cropping areas. Medium bush fire hazard areas are predominantly state forests and areas covered in remnant (indigenous) vegetation. It is noted that none of the Surat Gas project development area is classified as *high hazard* zones.

From a bush fire risk point of view, the developments in the Surat Gas Project development area is acceptable in l*ow* to *medium* bush fire hazard areas provided State Planning Policy 1/03, *Mitigating the Adverse Impact of Flood, Bush Fire and Landslide* (Ref 30) in managing bush fire risks are implemented. The following controls will be applied to minimise the risk to people, plant and equipment from bush fires:

- Emergency response plans will be established for each site and will document the appropriate action to be taken in case of a pending bush fire in the area. The action will either be to keep up production as flowing pipelines are less likely to be affected by a nearby fire than non flowing pipes, or, if safer to do so, shut down.
- In case of a major bush fire, gas wells and other facilities may be shut in in advance by operating the isolation valve (if safe to do so). The isolation valves are to be fire proof (affording about 90 minutes of protection in case of a fire);
- The vegetation in the area around the sites will be managed in order to limit the fuel in the area by clearing from major vegetation (e.g. trees, and large bushes). The distances of cleared vegetation will be determined on a site by site basis depending on the perceived fire risk in the area, using a matrix based risk assessment approach. Arrow will consult with rural fire brigades and/or local Fire Brigades in this regards.
- As part of the maintenance regime the gathering line easement will be cleared of any major vegetation. This will minimise the threat posed from a bush fire on the gathering system. Further, the gathering line, being buried at a depth of at least 600mm, is unlikely

to be affected by a bush fire due to the dissipation of heat from the fire through the soil cover.

8.4.2 Risk of Flooding

With very large quantities of water contained on the IPF site there is a risk of failure of dam walls and subsequent flooding of the site. Such risks are heavily controlled through dam safety guidelines.

Further, the application of State Planning Policy 1/03, *Mitigating the Adverse Impact of Flood, Bush Fire and Landslide* (Ref 31) will apply for all facilities forming part of the present development.

8.4.3 Road Transport Risk for Potentially Hazardous Material

There will be minimal road transportation of hazardous material associated with this development. The risk associated with such transportation is very small and is managed through standard procedures by the transport companies.

8.4.4 Risk of Initiation of Bush Fires

Bush fire would pose a risk to on-site populations (staff, contractors, visitors). The Surat Gas Project development area is categorised as *medium* to *low* bush fire risk. All of the proposed gas developments are acceptable in l*ow* to *medium* bush fire hazard areas provided State Planning Policy in managing bush fire risks are implemented.

For these risks, Arrow will apply internal safety management systems, including preparing contingency plans.

The use of access tracks, in particular during construction and maintenance activities at the wells and during construction of the pipelines, may impact on the surrounding natural environment. Further, it is possible that vehicles and machinery used during these activities cause a bush fire. Arrow will manage vegetation around above ground facilities and power poles. Procedures will be established to ensure control of activities during extreme fire danger periods. These measures serve to manage this risk.

8.5 Risk During Operation and Maintenance Risk During Decommissioning

Risks during decommissioning are very similar to the risks during installation, as discussed in Section 8.2 above.

These risks include failure to follow purging procedures as well as general safety hazards encountered during construction from uneven ground and the presence of venomous snakes and spiders, and the use of heavy machinery, electrical equipment and rotating equipment.

There are also risks to workers during decommissioning of wells, gathering system, CGPF, IPFs and high pressure gas pipelines from potential ignition of flammable gas which need to be assessed and managed prior to introduction of a source if ignition.

No risks with off-site consequences (such as those associated with fire, explosions or release of hazardous materials) have been identified for the decommissioning and rehabilitation stages for this development. Hazards for personnel and contractors involved with this work would be managed using Arrow safety, health and environmental procedures and protocols, JSEAs and Permit To Work procedures.

9 RECOMMENDATIONS

To ensure an acceptable risk associated with the proposed facilities which form part of the proposed development, a number of assumptions with regards to risk management measures have been made throughout this PHA. These assumptions have been formulated in the form of recommendations below, as follows:

Recommendation 1: Design pressure of pipe and equipment in gas usage shall be at well above the maximum operating pressure of the plants and equipment, to be defined in Arrow design documentation

Recommendation 2: Overpressure control of the gas wells should be provided in the form of PSVs on the gas line and on the separator. These should be set to protect downstream equipment and be designed to relieve the full flow from the well. It is recommended that they are designed to vent to *safe location*, i.e. away from people and potential ignition sources, allowing the gas to safely disperse.

Recommendation 3: It is recommended that at least the emergency isolation valves at the battery limits for the CGPF should be *fire proof*, providing prolonged integrity in case of exposure to a fire (at least 90 minutes).

Recommendation 4: A major incident at a compressor or at the export pipe between the compressors and the battery limit should initiate an automatic Emergency Shut Down and flaring of the contents in the affected plant to safe location (this is relevant for each of the FCFs, CGPFs and the IPFs). Each compressor should be fitted with isolation valves at the inlet and the outlet of the compressor, which should be set to shut in case of a major incident, and the affected compressor to flaring.

Recommendation 5: Hazardous area classification drawings should be prepared for all plants where flammable gas may be present, including where the gas is released after transportation in the water stream. All electrical equipment should be fitted and maintained in accordance with hazardous area codes and requirements.

Recommendation 6: Adherence to Arrow risk management systems and procedures should be strictly checked during construction and operation of all facilities, with particular attention to Permit to Work and Control of Modification management.

Recommendation 7: Maintenance of all plant and equipment should be performed according to a set protocol and shall include visual inspections through to non-destructive testing techniques. Any flexible lines (e.g. on gas wells) should be included on a critical maintenance register. A systematic maintenance and testing program should be established for all local and remote control and monitoring systems.

Recommendation 8: Technical personnel should be trained in what constitutes *critical safety equipment* such as gas and fire detectors and that the removal of any such item must be controlled through the Permit to Work system (or other suitably managed system).

Recommendation 9: It is recommended that the gathering pipeline's risk management systems align with the requirements under AS2885 (gas and liquid petroleum pipelines). For example, the gathering system should, where possible, be registered with Dial Before You Dig (or equivalent system); sign posts should be placed along the pipelines; and a *location and threat analysis* should be performed (following the general techniques set out in AS 2885.1) before deciding on the routing of any part of the gathering system.

Recommendation 10: Atmospheric storage tanks used for potentially polluting or hazardous material should be bunded to appropriate Code requirement (e.g. AS1940 for combustible liquids and AS3780 for corrosive water treatment chemicals). Bunds should be kept closed at all times (except during controlled discharge of clean rain water) – adherence to this requirement should be regularly audited.

Recommendation 11: Minimisation of the risk to people, plant and equipment from bush fires should be achieved through the preparation of emergency response plans, including planning for evacuation and determining the appropriate action to take with respect to either keeping up production or, if safe to do so, to shut down and vent. This may be achieved through the implementation of State Planning Policies in managing bush fire risks.

Recommendation 12: Fire breaks and fuel (timber, grass etc.) management of the area around the wells, the gathering line easement, the FCFs, the CGPFs and the IPFs should be determined in conjunction with Rural Fire Services.

Recommendation 13: The compressor areas should be hard stand gravel (no grass) and the maintenance plan for the sites should include the requirement to remove combustible materials and vegetation from the site.

Recommendation 14: In order to minimise the likelihood of a leak at the wells it is recommended that the pipe-length between the well head and the flow control valve is minimised; that the number of connections used on the wells is minimised; that, wherever practical, flanges are used instead of screwed connections; and that wherever possible, hard-pipe are used instead of flexible lines. These requirements should form part of design guidelines.

Recommendation 15: The fence surrounding the gas wells should be constructed such that the Hazardous Zone (as per Area Classification) is contained within the compound.

Recommendation 16: Assess the practicality of including an automatic response to a fire scenario at the gas wells in the form of an automatic isolation of the well. Note that the predominant factor influencing the risk is associated with jet fires – therefore the detection needs to be able to pick up the presence of a flame. Methods that should be reviewed include burn-through nylon tubing.

Recommendation 17: Scheduling of internal and external audits to ensure that the safety management systems are functioning properly and that it is appropriate to the hazards associated with the facilities. Detailed specialist audits of engineering and safety issues should be carried out at regular intervals not exceeding every four years with the first audit conducted within six months to one year of commissioning of the first facilities. The detailed specialist audit should be conducted in accordance with recognised audit methodology, such as that described in the Department of Urban Affairs and Planning, Hazardous Industry Planning Advisory Paper No. 5: *Hazard Audit Guidelines*; 1993 Edition (32)

Recommendation 18: Construction and commissioning safety management plans to be developed for each type of facility associated with this project.

Recommendation 19: Fire safety requirements for each type of facility to be established in conjunction with the Rural Fire Brigades and the local Fire Brigades.

Recommendation 20: Emergency plans to be developed for each type of facility. Site-specific details will need to be included.

Recommendation 21: HAZOP (Hazard and Operability) studies to be conducted during detailed design of each type of facility forming part of the present development proposal.

Recommendation 22: Trips and alarm philosophy as well and venting and relief requirements to be established during detailed design.

Recommendation 23: In AS1940, process vessels are not required to be bunded. However, as glycol is used hot in the process it is recommended that bunding is installed to contain the glycol in case of a spill. Bunding design and construction to (at least) conform to AS1940 requirements.

Appendix 1

Design and Legislation

Preliminary Hazard and Risk Assessment of

Arrow's Surat Gas Project, QLD

Appendix 1 – Legislation and Safeguards

A1.1 Codes and Standards

The main risk management standards and guidelines as well as the main acts and regulations that form part of the present development are presented in Section 1.3.2 in the main body of the report.

The main Australian Standards are presented below:

- AS 2885 Pipelines Gas and Liquid Petroleum
- AS 4130 PE Piping Systems
- AS 2033 Installation of Polyethylene Pipe Systems
- AS 1210 Pressure vessels
- AS 3000 Electrical Installations (Australian wiring rules)
- AS 2381 Electrical equipment for explosive gas atmospheres – Selection, installation and maintenance.
- AS 2430 Classification of hazardous areas
- AS4564 Specification for general purpose natural gas
- AS3814 Industrial and Commercial Gas Fired Appliances) Design

A1.2 Engineering Design

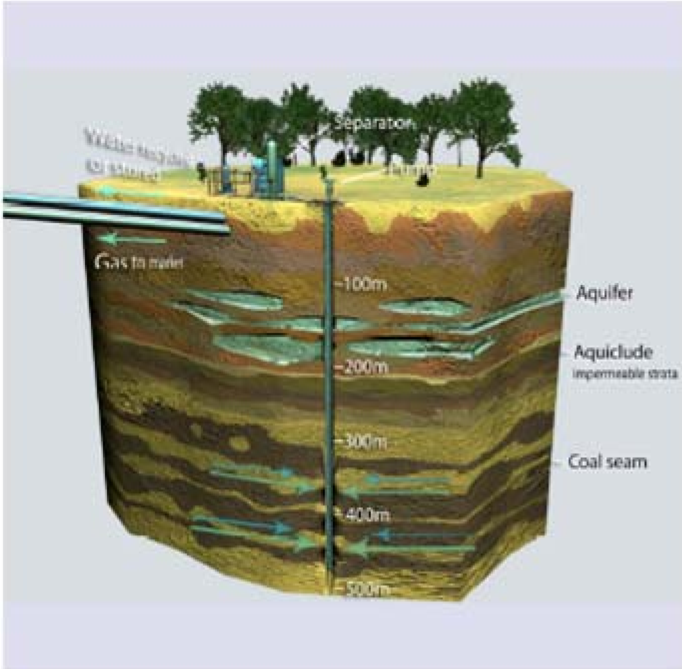
A1.2.1 Configuration, Gas Well

Over the whole project development area there will be approximately 7,500 wells. Wells may be spaced between 700 m and 1,500 m apart, which provides flexibility in their placement. This equates to an indicative density of one well per 160 to 320 acres (65 to 130 ha). Production wells will be located greater than 200 m from any sensitive receptor. The actual physical location of wells will depend upon review of environmental constraints mapped together with consideration of safety and landholder requirements. To ensure safe operation of the drilling rig and associated equipment, drilling sites are normally prepared with dimensions of typically 70m by 60m (or even up to 85m x 85m) - this is an area that is sufficiently large enough for the truck mounted drilling rig with space around the rig for work related access and safe movement and materials handling.

Production wells are nominally drilled 300 to 600 m deep (depending on the coal reserves). To prevent the loss of water from upper groundwater aquifers, the top section of each well is cased with steel and cement.

A cross sectional view of a gas well site is shown in Figure A1.1 below CSG is a form of natural gas formed and trapped in coal beds by water and ground pressure. A casing and tubing arrangement is inserted into the drilled hole. Water is pumped out from the bottom of the well, which lowers the pressure in the coal seam, enabling gas to flow up to the surface. The water is then separated from the gas and each process stream is fed into a separate flow line.

Figure A1.1 – Cross Section of Coal Seam Gas Well Site

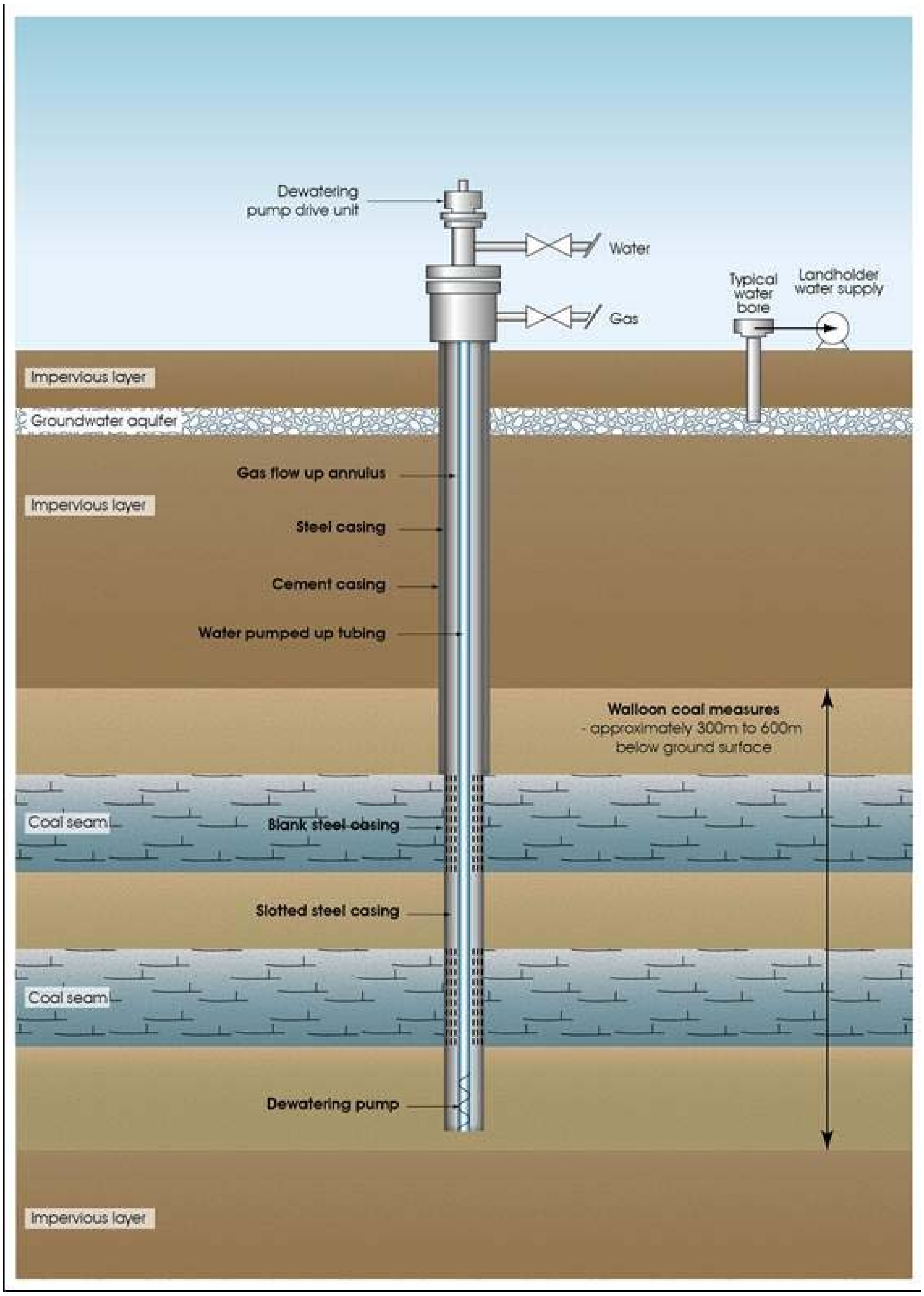


The CSG well typically includes a casing and tubing arrangement, a wellhead collar, a gas/water separator, a gas powered generator (or equivalent power source[38]), an electric top drive water pump and flow lines for water and gas. The well head collar connects the casing and tubing to the well head manifold, complete with local and remote operated shut down valve, pressure control, gas and water metering, a communication unit and a control unit transmitting data to a Control Room which is monitored 24/7. The water separator (with pressure relief) is used to separate water from incoming gas[39]. A gas line and a water line connect the water separator with the gathering system, including pressure control and pressure relief. A schematic of the gas well is provided in Figure A1.2 below.

[38] The power source (i.e. pump) can be removed in case of wells with good flow capacity.

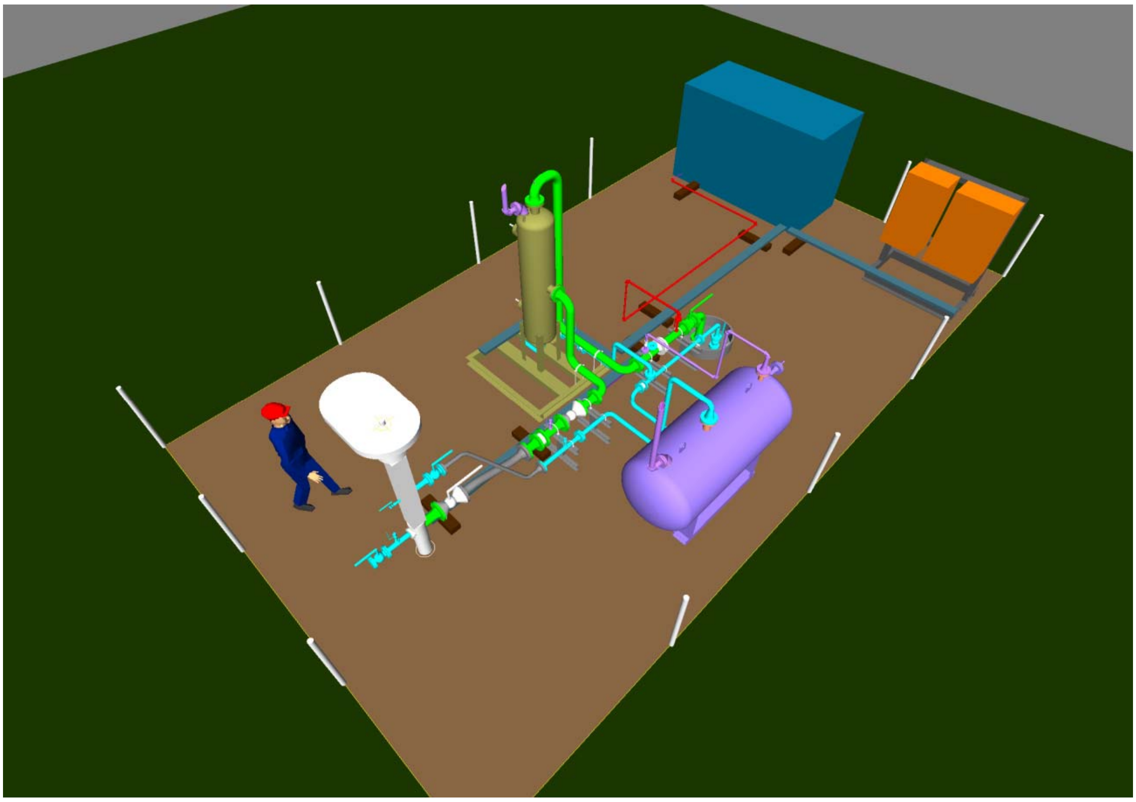
[39] A gas separator vessel may also from time to time be required to separate the gas from the water stream. The gas separator is placed on a skid to allow for easy mounting onto the CSG well piping.

Figure A1.2 – General Configuration of Coal Seam Gas Wells



The well site will located within a fenced compound. The general arrangement around the well site is shown in Figure A1.3 below.

Figure A1.3 – Preliminary Well Head Arrangement



White upright: well head with top-mounted pump motor; purple tank: water degasser; beige tower: gas separator; Blue box: power generator (fuelled by CSG – only present if centralised power generation is not used); Orange box: switchboards.

Equipment used to install production wells includes:

- Site preparation: Earthmoving equipment such as graders, excavators and bulldozers;
- Production well drilling: 50 t truck-mounted drilling rig or hybrid rig, casing trucks, mud tanks, huts and water trucks;
- Well completion: Approximately 20 to 30 t truck mounted rig, water trucks, delivery trucks, tubing and rod strings, drive head and associated consumables;
- Surface equipment installation: minor earthmoving equipment, gravel trucks, delivery trucks, mechanical and electrical installation equipment;
- Well site rehabilitation: Earthmoving equipment such as excavator, truck (tipper), grader and tractor with seed distribution equipment.

Production well drilling involves:

- Drilling to the productive strata (typically from 150 m to 750 m below ground surface).
- Casing and concreting the well through the non-productive strata.
- Completion of the well in the production zones.
- Fitting of wellhead for connection to surface equipment.
- Using surface tank collection of drilling muds (on intensively farmed land). In other areas, pits for water and drilling muds would be constructed.

On completion of drilling, the well site will be partially rehabilitated to a nominal 10 m by 10 m area (based on landholder compensation principles) that will be fenced to exclude stock and unauthorised access. Arrow Energy will select fencing of an appropriate height and type depending on the location of the production well i.e., normally 2.1 m high galvanised / painted steel and including mesh where wells are easily accessible to the public.

Gas generators will be used to supply power to production wells (for dewatering pumps and ancillary equipment) until the gas free-flows, after which, production wells will be powered by solar panels where possible, to maintain communication systems. Well head equipment will either be powered by the gas generators noted above or from the electricity grid via above ground and underground cabling.

Throughout the operation of the well, a work-over rig may at times will be required to perform a variety of downhole functions such as washing of the production casing to the total depth of the casing to circulate sand or debris from the well; and installation of downhole pumps.

Please note that **no** hydraulic fracturing (*fraccing*) will occur in the Surat Gas Project development area. As discussed in the EIS, the depth and permeability of the coal makes the process unnecessary.

A1.2.2 Configuration, Gathering System

Water, gas gathering lines, electrical and communications connections will be installed to link the well back to the CGPFs and the IPFs.

Low pressure water and gas lines will consist of high density polythene (HDPE) lines of a diameter ranging from 100 mm to 630 mm. Low pressure gathering lines will be used to deliver gas directly from production wells to either central gas processing facilities or integrated processing facilities at a pressure not exceeding approximately 100 kPa for gas and 600 kPa for water. Where required, the gas may flow via the field compression facilities (FCFs) to boost the pressure in the line allowing it to reach the central gas processing facilities or integrated processing facilities for treatment.

To allow for the higher pressure at the outlet of the FCF (approximately 1,000 kPa (g) medium pressure gas pipelines will be installed downstream of these booster pressure facilities up to the CGPFs or IPFs for treatment. Medium pressure gas pipelines will be constructed of a lightweight, strong, plastic composite, glass reinforced epoxy (GRE) or lined steel.

A typical 15 m right of way is required for low pressure gathering line installation and a typical 20 m right of way is required for medium pressure gas pipeline installation. For areas of environmental sensitivity, the right of way can be narrowed (through the area of sensitivity).

Marker tape, surface signage, low point water trap, high point gas vents and low point water drainage capabilities will also be installed.

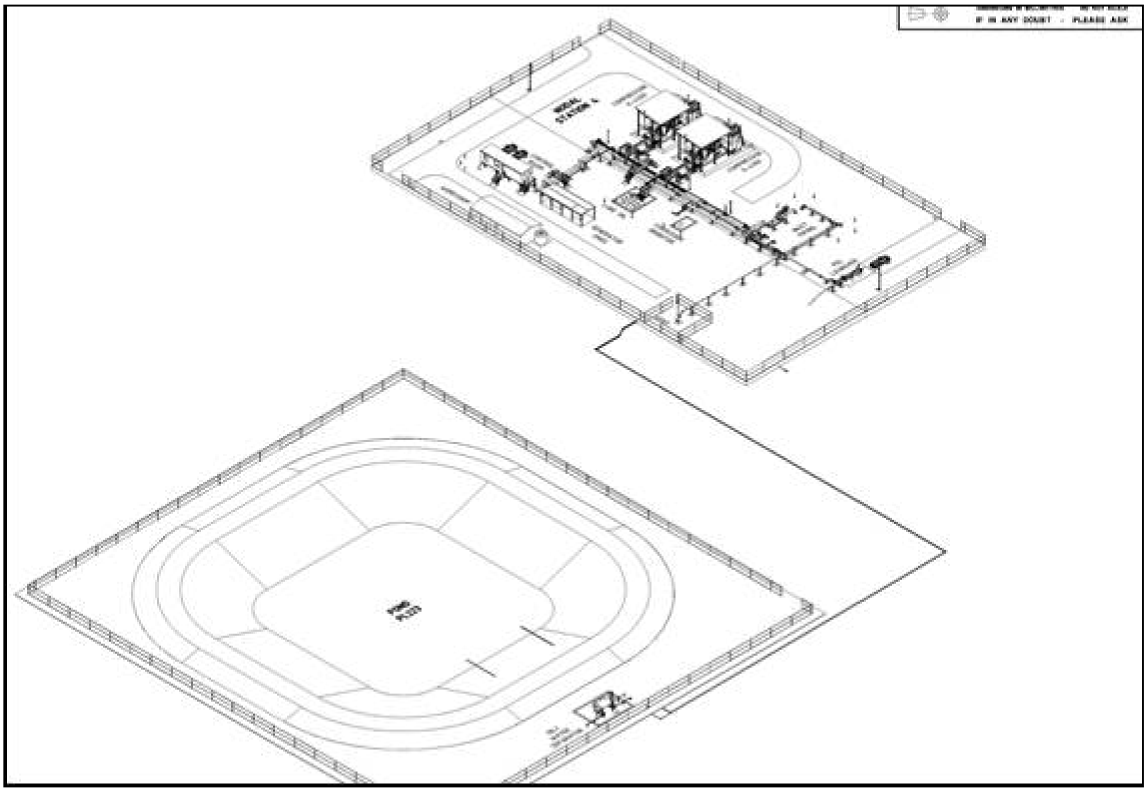
The gas lines will be buried in accordance with the requirements of AS/NZS 2885 and/or 3723-1989, typically at a depth of at least 750 mm. Prior to commissioning the gathering systems will be hydrotested to ensure operational integrity. Normal operating pressure will vary throughout the gas gathering system. It will have a maximum allowable operating pressure (MAOP) of 1,000 kPa.

A1.2.3 Configuration, Field Compression Facility

A preliminary plot plan of the FCF is provided in Figure A1.5 below. This plot plan shows a typical layout with two compressors. The actual number of compressors may change depending on the pressure demands and supply and ay extend to 3 to 6 screw compressors and 1 to 2 reciprocal compressors.

The present assessment has modelled the risk of a FCF comprising only two compressors (as per the lot plan below) as well as the risk of one that comprises up to eight compressor units, refer Section 6.4 of the main body of the assessment.

Figure A1.5 – Approximate Layout of Field Compression Facility



Flows through the field compression facilities are likely to be between 30 and 60 TJ/d.

Field compression facilities (FCFs) are located between wells and central gas processing facilities or integrated processing facilities where wellhead pressure is not sufficient to transport the gas over the required distance to central gas processing facilities or integrated processing facilities.

Field compression facilities will be constructed of skid-mounted modules to minimise onsite construction and periods of disturbance. FCFs will be operated remotely with manning for maintenance purposes only. Field compression facilities may serve as a base of operations for field personnel and could accordingly incorporate facilities such as offices, crib rooms, and storage.

A1.2.4 Configuration, Central Gas Processing Facility

There will be up to six CGPFs to service the Surat Gas Project development area.

Central gas processing facilities receive gas from either the field compression facilities (via the medium pressure gas pipelines) or directly from the gas wells (via the low pressure gathering systems).

The gas is dehydrated, compressed to high pressure (about 10,200 kPa), and discharged to one of two high pressure pipelines (i.e. the Surat Header Pipeline or the Arrow Surat Pipeline). Central gas processing facilities flows are expected to be between 30 and 150 TJ/d.

Central gas processing facilities are designed to perform the following functions:

- Receipt of gas and water directly from wells or from the wells via one of the field compression facilities;
- Compression of gas in multiple compression trains with both first and secondary multistage compression (to a Maximum Allowable Operating Pressure of 10,200kPa);
- Treatment of gas in one or more dehydration units (using tri-ethylene glycol (TEG) contacting column with the dry gas being directed to metering and distribution management. The TEG is continually regenerated, which involves distilling off the absorbed water at low pressure. A filter (coalescer) downstream of the contacting column recovers any entrained TEG and returns to the regenerator;
- Discharge of gas to one of the two high pressure pipelines;
- Piping of water to a water transfer station and further towards the IPF;
- Generation of power (from produced gas) and distribution for use in the facility and the field (Refer Section 0 below).

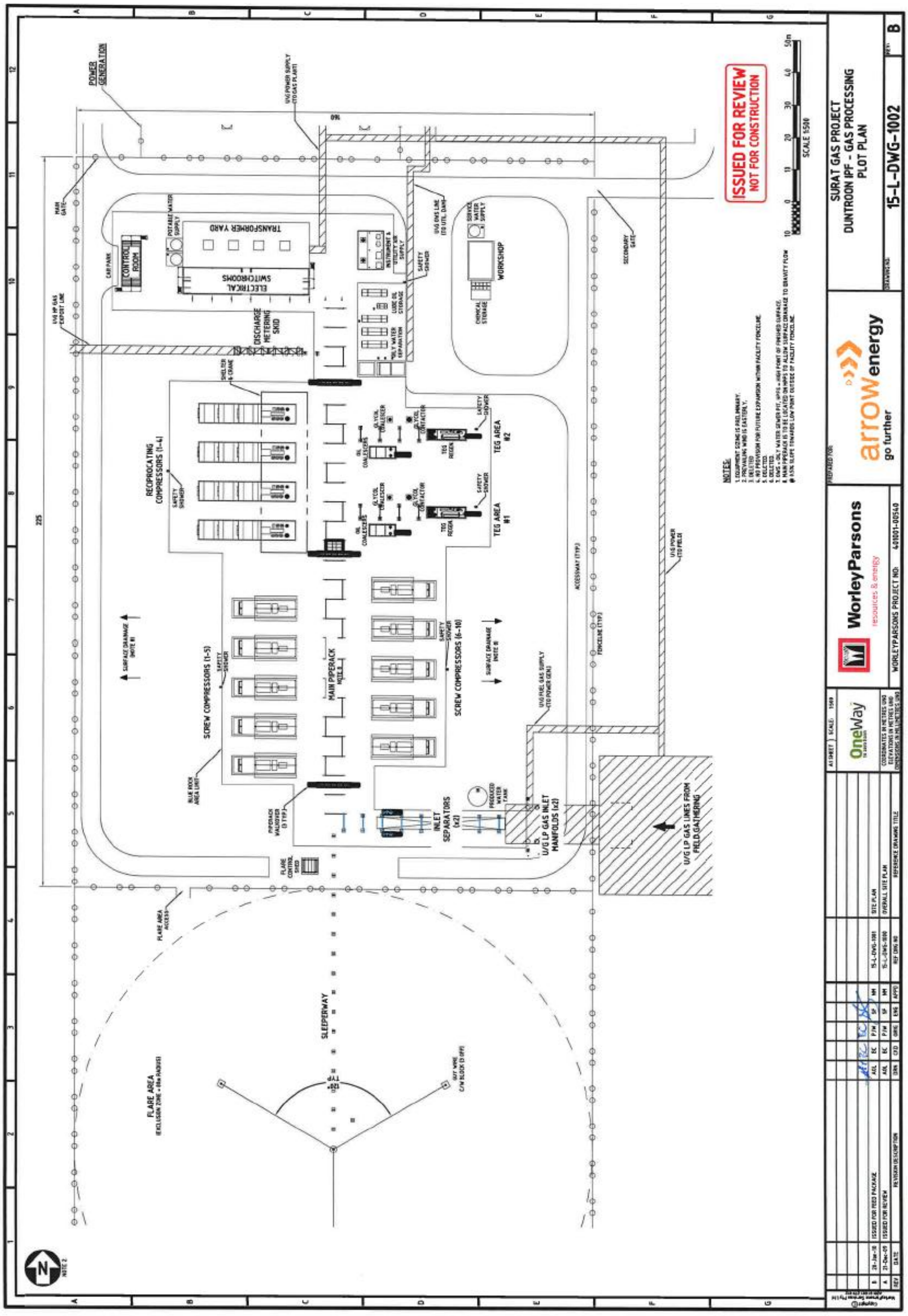
Each CGPF processes gas from (typically) 50 wells. Each CGPF will operate 24 hours a day, seven days a week, with regular partial shutdowns of plant equipment for maintenance and repair work.

Production facilities will be constructed of skid-mounted components. In general, 30 TJ/d compression modules will be used. The modular approach will reduce construction times and is expected to allow the movement of compression trains to different parts of the project development area during the life of the project. It will also provide flexibility to adjust facility size during development as production ramps up and to cater for subsurface uncertainty. The number of compressors shall be minimised (largest practicable machines) with up to 12 compressors[40] operating at each CGPF.

A preliminary plot plan of the CGPF is provided in Figure A1.6 below. This plot plan shows a typical layout with ten screw compressors and four reciprocal compressors. The actual number of compressors may change depending on the pressure demands and supply, as shown in Table 8 above. The figure shown below is based on an IPF with the CGPF included.

[40] A combination of screw compressors and reciprocating compressors will be used. One spare compressor of each type will also be installed.

Figure A1.6 – Indicative Plot Plan of Central Gas Processing Facility



Although the facilities will operate 24 hours, 7 days a week, the facility will be generally manned over a 10 hour day shift with a call out facility to ensure response to plant upsets. Responsive maintenance and emergency maintenance can be conducted at any time. The new facilities will be designed for automated, unmanned operation, with operating information transferred electronically to central operating personnel remote from the facility (manned 24/7). It is likely that existing infrastructure will continue to be manually monitored, with the option for the existing facilities to be retrofitted, allowing automatic monitoring in the future.

Approximately seven to nine persons are expected to be required for operations, maintenance and management of each gas processing facility.

Routine operation and maintenance activities include general inspection of the facility for correct operation, to confirm on-line controls are working correctly, and correct quality of gas are being produced.

Non-routine and infrequently scheduled activities include responding to warnings/alarms received on the remote monitoring system, internal equipment inspections to confirm equipment integrity and/or meet statutory requirements, instrument checks/calibrations, replacement of consumable items, and repair or overhaul of mechanical equipment such as pumps and motors after long periods of operation.

In the case of planned maintenance, gas flows would be reduced in advance of the planned shutdown by reducing or stopping gas flow at the CSG gas wells.

The CGPF comprises an automated emergency shutdown (ESD) system including remote monitoring and control flow and pressure instrumentation to transmit upset condition and plant shutdown valves, fire/gas detection system around compressors to shutdown compressors and other automated safety features.

A1.2.5 Configuration, Integrated Processing Facility

The term integrated is used as the facility contains both gas processing and water treatment facilities.

There will be up to six IPFs to service the Surat Gas Project development area. Their exact location is yet to be determined. Each IPF will incorporate a CGPF. With respect to CSG handling and treatment, the IPFs will operate in an identical manner to the CGPFs (with the exception that more compressors may be installed at the IPFs than at the CGPFs).

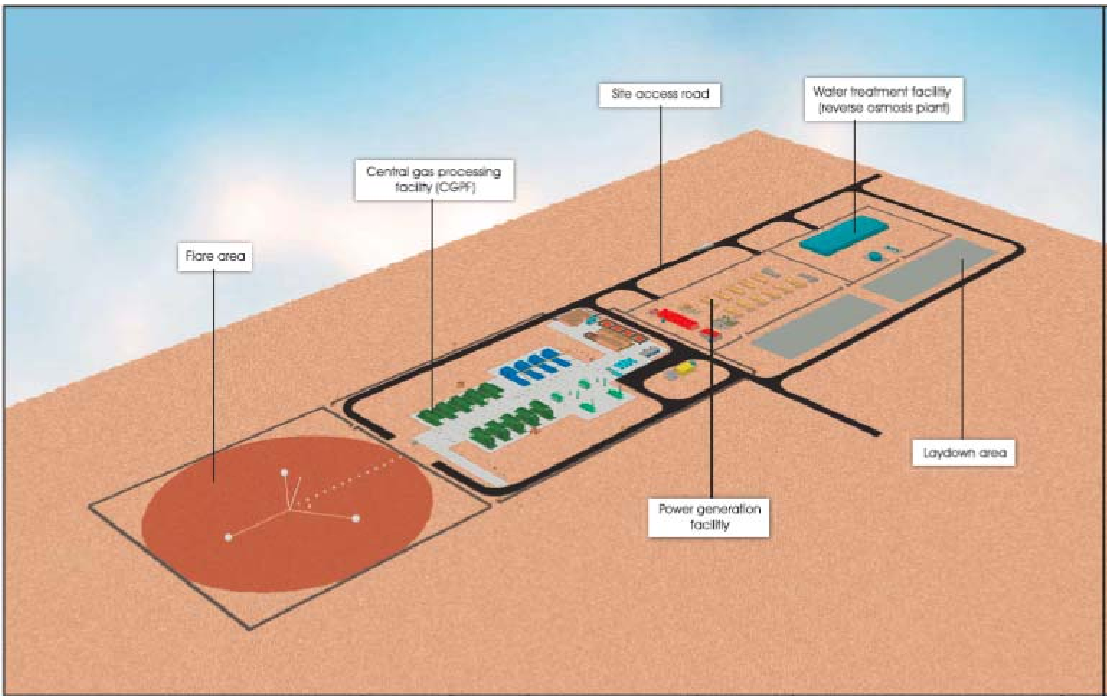
With respect to water handling and processing, the IPFs are designed to perform the following functions:

- Treatment and processing of water;
- Storage of water in dams;
- Discharge of treated water for beneficial use or disposal as described in Section 4 of the EIS (*Coal Seam Water Strategy).*

The IPFs will also generate power (from produced gas) and distribution for use in the facility and the field.

A preliminary plot plan of an IPF is provided in the figure below.

Figure A1.7 – Indicative Plot Plan of Integrated Processing Facility



Water Treatment Facility: Up to 20 water treatment plants will be installed across the project development area. Water from the adjacent wells is received at the feedwater dam. This dam provides for surge capacity, solid dropout and salt composition equalisation. From the feedwater dam, water is transferred into water treatment facility (filtration and reverse osmosis units), which remove particulates and salt to produce clear water and a concentrated brine stream.

The clear water is received in a clear water dam before being transferred to end users in the local area. Concentrated brine is received in a brine dam, where the salt concentrates through the evaporation process prior to ultimate disposal at licensed off site waste facilities. The design retains flexibility for enhanced brine recovery through vacuum distillation or salt crystallisation. A separate pond is also in place to manage oily water from the compression plant, power plant and chemical waste from the water treatment plants.

Power Supply: The gas processing, water treatment and, at times, field facilities will be powered by power generating facilities, generally located at the IPFs. The installed power capacity at each IPF is expected to be in the order of 10 - 48MW. An estimated eleven generators (ten on duty and one stand-by) will be installed at each IPF.

The power generating facilities generate power through the use of gas engine style generators. Fuel to the generators will be directly supplied from the inlet to the generator facilities. The generators will be installed in acoustic enclosures. Where it is feasible to do so, power from the facilities will be distributed to the adjacent field via a combination of overhead and underground cabling.

The power generating facilities and electrical infrastructure will be configured to enable maintenance to be conducted during downstream LNG liquefaction plant planned slowdowns (expected every 6 months).

An alternative power supply option for the Surat Gas Project is to connect to existing 132 kV transmission and/or distribution infrastructure. Connection will be coordinated with transmission and distribution network service providers. It is envisaged that substations will be established by connecting to the existing transmission network to supply electrical substations on Arrow Energy's petroleum leases in the vicinity of central gas processing and integrated processing facilities at strategic locations throughout the project development area. Establishment of the substations and the high voltage transmission lines (e.g. 132 kV) that will connect the substations to the electricity transmission grid are outside of the scope of the EIS. Electricity will be distributed from the substations to zone substations established at or near central gas processing and integrated processing facilities via a highly reliable system to ensure adequate reliability of the power to those facilities.

A1.2.6 Gas Flaring

A flare will be in place on each CGPF and IPF only for the purpose of upset conditions / emergency events or in the event of controlled flaring off of excess gas.

Please note that the flare is not required for emergency situations. All emergency vents (tailpipes, equipment depressuring) is done through locally mounted vents where the gas is dispersed appropriately at a height away from people and away from potential ignition sources.

The flare is expected to be a pipe flare with continuous pilot ignition and a water seal for reverse flow protection. It will be to be sized for a full facility inflow capacity. All flare systems will be designed to operate in accordance with the *Queensland Petroleum and Gas (Production and Safety) Act 2004.*

A1.2.7 Configuration, High Pressure Gas Pipelines

The high pressure gas pipelines will connect the IPFs (or, if stand-alone, each CGPF) with the Arrow Surat Pipeline. These high pressure gas pipelines will be constructed in steel and designed in accordance with AS 2885.1 requirements, including a minimum depth of burial of 750mm (or 450 mm in rock). Locations chosen for above-ground facilities (i.e. valve stations) will consider visibility and access. The metering stations are likely to be fitted with intruder alarms to indicate unauthorised access.

The high pressure gas pipelines will be designed, constructed and operated in the same manner as the Arrow Surat Pipeline, details provided in the Environmental Impact Statement for the Arrow Surat Pipeline.

Appendix 2

Risk Management and Control

Preliminary Hazard and Risk Assessment of Arrow

Energy's Surat Gas Project, QLD

Appendix 2 – Risk Management and Control

The risk management strategy for the hazardous incidents identified during construction, operation and decommissioning is detailed in each Hazard Identification Word Diagram in the main body of the report.

Some further details as to the risk management strategy are provided below:

A2.1 Management of Loss of Containment Risks Due to Pipe and Equipment Failure

Pressure piping may fail as a result of corrosion, erosion, mechanical impact damage, pressure surge ("water hammer") or operation outside design limitations of pressure and temperature. Pressure surge or significant deviations of pressure or temperature may cause a joint to be overstressed, resulting in a small leak. Corrosion and erosion caused failures usually result in small leaks, which may be corrected provided they are detected in time. If they are allowed to continue they may develop into larger leaks – hence inspections and patrols on a regular basis is paramount for safety at gas wells. Larger holes through to complete line fracture may conceivably result from mechanical impact or pressure surge.

The ability to automatically shut in the leaking section of pipe or plant and vent in case of a major leak, thereby limiting the amount of gas released to relatively small quantities, is important to manage the risk associated with a facility. Emergency stop buttons will be located at strategic locations on FCFs, CGPFs and IPFs. Fire and gas detection with automatic response will be installed at FCFs, CGPFs and IPFs as appropriate.

The likelihood of an explosion inside one of the compressor units is virtually eliminated or at the very least reduced to an absolute minimum through design. This entails minimising the likelihood of a leak and the probability of reaching Lower Flammable Limit (LFL). Compressors will not be enclosed to reduce the gas concentration. There will be compressor unit shutdown and venting in the event of excursion from normal operation.

The following procedural controls are associated with the facilities: Testing of each relief valve (and re-testing after it has been activated); Scheduled visual inspection of pressure piping and fittings; Maintenance and inspections programs including Non-Destructive Testing programs of pipes and valves; Regular leak testing; Ultrasound thickness testing program for fittings; Pressure vessel inspection programs; Systematic compressor inspection and preventative maintenance program; Systematic maintenance and testing program for all local and remote control and monitoring systems; Pre-start-up purging of all lines and equipment (and purging prior to any hot work being carried out on pipes which have contained flammable gas); Safe work practices, including Permit To Work (and hot work permits) to ensure ignition sources are appropriately controlled during maintenance, equipment testing; and Job Safety Analysis (or similar technique) is performed before carrying out major maintenance activity and control of modification system in place to control any changes to installation design and set-up.

Separation distance between the facilities and sensitive locations aid in minimising the extent of damage should an incident occur. The separation distance limits the extent of the damage in the event of an incident.

A2.2 Management of Pressure Vessel Failure Risks

Any excess pressure in pressure vessels (e.g. the separator at the well) will trigger an opening of the pressure relief valve, and the gases will be discharged at height (to allow for safe dispersion at height away from people and away from potential ignition sources).

Pressure vessel may suffer from failure due to corrosion, erosion or mechanical impact. Major incidents involving the vessel include catastrophic failure and leaks. Pressure vessels are subject to regular inspection including NDT programs. This is as per Code requirements for pressure vessels and will be integrated into Arrow Energy's Preventative Maintenance (PM) strategy.

Corrosion and erosion caused failures usually result in small leaks, which are detected early and corrected.

The following technical controls apply: pressure vessels have a design pressure rating at least equal to it's maximum operating pressure; a PSV is fitted to each pressure vessel in accordance with Code requirements; non-destructive testing and visual inspection of pressure vessels are carried out.

A2.4 Management of Risk of Confined Explosion in Pressure Piping

General

An explosion in vessels or within pressure piping is theoretically possible during start-up, shutdown and maintenance operations as during decommissioning and purging of the facilities. As a procedural control there will be a pre-start up (or pre-decommissioning) of purging of all lines and equipment. This will occur if piping and vessels have been or will be exposed to air.

Within Process Equipment at FCFs, CGPFs and IPFs

An explosion in a vessel or pipe is possible during start-up, shut-down and maintenance operations. However, as all piping will normally operate at a positive pressure, thereby preventing ingress of air in the event of a pipe or other equipment failure and as if the gas pressure drops at the inlet to the compressor (such as in the event of an upstream failure) it will automatically shut down, thereby preventing ingress of air, ingress of air would be highly unlikely to occur during normal operation.

Further, ignition sources will be controlled so that they are not present where explosive gas/air mixtures exist. Appropriate earthing design is required to discharge static electrical fields from vessel.

Hence, the risk of confined explosion in piping and vessels during normal operation which could affect areas outside of the boundary is nominal.

However, the risk of a confined explosion would pose a threat to operator and workers within the facility and its prevention should be considered throughout the design and operation of the facility (for example in the preparation of start-up, shut-down and maintenance procedures).

Within a Generator Enclosure

Despite the best efforts during design and management of the generator, natural gas engine failures can occur in operation but are an infrequent occurrence. The generators will be enclosed in acoustic chambers to reduce noise introducing a degree of confinement. Ignition of gas fuel released into the enclosure can cause fire and, because of the confinement, even explosions.

The basis of safety of generator enclosures is generally achieved through a combination of:

- Elimination or control of sources of ignition as far as reasonably possible[41], following legislative requirements and Australian Standard requirements for equipment in hazardous areas (particularly electrical equipment which will use an approved protection method such as intrinsically safe or non-sparking as appropriate);
- Limitation of the gas concentration of the explosive atmosphere by the application of dilution ventilation. This method dilutes the gas concentration of any emission of gas in the confines of the ventilated space, to a level below that which would result in a hazardous explosion if ignited.
- To ensure a negligible risk of an explosive atmosphere during operation, the ventilation system will be interlocked so that the unit can only be pressurised or operated when the fan is running. Additional safety features such as a 100% standby fan and/or an uninterruptible power supply to the ventilation fans can improve the unit availability in the case of a fan fault or power supply failure.
- Gas and fire detection system (duplicated for reliability) will invariably shut down the compressor at a gas concentration well below the lower hazardous limit.
- Preventative maintenance procedures and schedules will be developed for the proposed site, covering all critical safety functions such as gas detectors, ventilation fans, alarm systems, as appropriate.
- Operators and maintenance workers will be trained to recognise the critical nature of critical safety functions (such as a leak detector, ventilation fan). A system will be put in place to ensure that any removal of critical safety function (e.g. for repair or exchange) is approved by plant management (decision on whether to shut down an engine/compressor if a critical safety function is removed).
- The Arrow Energy Permit To Work (PTW) systems will be used for work inside and outside the enclosed areas (including engine/compressor housing).
- Emergency procedures and drills for personnel will be developed.

A2.5 Management of Risk of Ignition of Flammable Gas Entrained in the Water Stream

It is possible that small amounts of gas is transported in the water stream from the wells and transferred to the IPF dam used to collect the water. The following technical controls apply to control potentially flammable gas transported in the water steam: the water line is vented for removal of small amounts of gas; the dam is in the open and Hazardous Area Classification zoning (to Code requirements) will be established for electrical equipment and potential ignition sources; signs showing no smoking and the danger of flammable gas will be positioned. Further, control of visitors to the wells will apply.

A2.6 Management of Risk of Gas Well Pump Failure

Pumps, such as those operating at the gas wells, are used to lift the water from the well bore to the surface. Failures of these pumps rarely have the ability to cause a hazard, as the pump is sub surface mechanical screw with only the engine being mounted on the top of the well.

The following technical controls apply to control pumps used in gas well service: the pumps are located at the bottom of the well within the gas stream, hence a leak at the casing or at the seal will release gas into the bottom of the well, and while being an operational nuisance such a leak would not cause a release at the surface, only the pump shaft leak could result in a leak of gas

[41] Note that compressor engines generally operate at lower external surface temperatures and the great majority of the surfaces which may come into contact with a hazardous gas- air mixture will be less than the self-ignition temperature and thus not be able to be the source of ignition.

to the atmosphere; the pumps, where fitted, have an automatic pump shutdown in case of it starts pumping against a closed head (i.e. it becoming deadheaded) and; there will be systematic pump inspections and a preventative maintenance program which will pay particular attention to seal integrity.

A2.7 Management of Risk of Failure During Gas Well Workover Operation

Workovers are potentially hazardous operations that must be managed appropriately, particularly if the gas well is located within a populated area. The hazards associated with workovers include the potential for injury due to a release of pressurised water or material (surfactant, cement or diluted acid). Other hazards include leaks in testing equipment, causing release of gas. The workovers are unusual operations, particularly on a well that has been operating for some time. Tight control through procedures and JSEAs will be required prior to any remedial treatment. A blowout preventer (BOP – a highly reliable shut-off device) will be fitted to the well head for certain workover operations. Workovers are heavily proceduralised and carefully executed operations.

A2.8 Management of Road Transport Risks of Potentially Hazardous Materials

Once the facilities have been built and put into operation, the frequency of road transportation, of Dangerous Goods and other potentially hazardous material, to each site will be low.

Transportation will consist of the occasional oil top up and possibly the transport of some other material used for maintenance or cleaning. Note that oil will be transported to the site in relatively small quantities. Lubricating oils are used in both the compressor gear boxes and the gas fuelled engine sump.

It is noted that even though road transport of potentially hazardous material to each site may be low, as there will be up to 7,500 gas wells located within the project area, the overall transport frequency per site needs to be multiplied by this number to account for the transport to the overall site, amounting to a much larger number of transportation activities in the Surat Gas Project development area.

General transport risks of these materials are handled by transport companies' internal safety requirements. Clean up and incident management will be as per the transport company's procedures and the Australian Code for the Transport of Dangerous Goods (Ref 33) will apply.

The review of road transport risks concludes that the risk associated with the transport of dangerous goods and potentially hazardous material is low.

Note that general transport risk (i.e. not associated with Dangerous Goods or potentially hazardous material) is not within the scope of this assessment.

A2.9 Management of Loss of Containment Risks Due to Cross Country Pipeline Failure

Losses of containment at the gathering system may result in releases of flammable gas (CSG) to the atmosphere and/or of saline water to the environment.

The controls, which apply for the management of threats to the gathering system (both saline water and gas) are listed below:

Table A2.1 - Management of Threats to the Gathering System

Issue / Concern / High Potential Risk	Risk Management
3rd party involvement digging or trenching	At the locations where the pipelines travel along pastoral land, there is potential for agricultural equipment damaging a pipeline. Gathering system is managed in accordance with APIA Code of Practice (Ref 34) Further, continuous (24/7) monitoring of the pipelines, gathering system and installation of manual valves, allowing for isolation of a section of the pipeline.
Airplane accident / impact causes failure of pipe.	The pipelines are buried at all locations. Due to the dissipation of the energy from the aircraft into the deep soil cover, the risk to a buried pipeline from an aircraft or train crash is considered negligible.
Road vehicle (semitrailer, truck, bus) impact on buried pipe causing failure of pipe.	The pipelines are buried at all locations. Due to the dissipation of the energy from the vehicle into the deep soil cover, the risk to a buried pipeline from a vehicle crash is considered negligible.
Road vehicle (semitrailer, truck, bus) impact on exposed pipework causing failure of pipe.	Threat to exposed valve station(s) from impact incidents, e.g. from road vehicles to be considered in location specific analysis and rendered negligible through site selection. Risk management may include bollards or other type of physical protection for areas where exposed pipework are located in close proximity to roads.
Subsidence due to mining activity or earthquake.	Earthquake in the area where the pipelines are located may threaten the integrity of the pipeline. Mining activity in the area may cause land subsidence, which could pose a threat to the facility or the pipelines. Risk of subsidence and earth movement will be taken into account in the design and construction of the facilities.
Flange Failure or valve gland nut leak.	Risk management include scheduled visual inspection of pressure piping and fittings; regular soap-testing (at least about 6-monthly); external inspection via non-destructive-testing (NDT) of any pressure vessels associated with the gathering system and other pipelines (if appropriate), in accordance with AS3788:2001.
Vandalism / Terrorism / Sabotage	Security fencing of any exposed valve stations.
Incident at neighbouring pipeline	An incident at a neighbouring natural gas (or other) pipelines may cause a threat to the gathering system and needs to be taken into account and rendered negligible through the site selection process.

A2.10 Control of Ignition Sources

Ignition sources are controlled through:

- Design of site and equipment as per Hazardous Area requirements.
- Earthing.
- Lightning protection through the use of buried main earth grid installed around FCFs, CGPFs and IPFs sites. The main earth grid operates to equalise potentials and ground any lightning fault currents, with over-voltage protection on all critical items of electronics.
- Permit to Work requirements (including Hot Work permit).
- No smoking or naked flames allowed on site, and no spark ignition vehicles allowed in designated hazardous areas.
- Fenced off area with warning signs as per Australian Standards requirements.

- Compressor skid pipework is insulated from customer connection pipework on the eastern side of the building.

A2.11 Management of Risk of Compressor Failures

Multi-stage compression equipment will most likely be installed within the FCFs, CGPFs and IPFs. Compressors, as used for the gas service, may fail in one of three basic ways:

- First, the compressor seal may fail and leak flammable gas.
- Second, the compressor casing may develop a hole due to corrosion or erosion.
- Third, the compressor shaft may fail, resulting in a hole size equal to the shaft diameter.

Over and above the controls listed above for pipes and fittings, the following technical controls apply to control of the compressors used in gas service:

- The compressors have an automatic shutdown in case of it becoming deadheaded;
- Compressors are fitted with anti-surge protection to prevent damage;
- Systematic compressor inspection and preventative maintenance program, paying particular attention to seal integrity;
- The compressors are fitted with a PSV and can be isolated and vented to a safe location.

A2.12 Incident Involving Combustible Liquids

Apart from CSG the only other main fire risk relate to the use of ethylene glycol, diesel and lube oil. Less than 10m^3 of tri-ethylene-glycol (TEG) is used as a dehydration agent for the gas and is held within the following process equipment:

There is no storage tank as such but the surge drum may possibly be regarded as a tank even though it forms part of process equipment. TEG is used in the process at 185^{o}C (well below its boiling point).

The following controls apply to the management of risks associated with handling and transport of flammable liquids (TEG, diesel and lube oil). All the requirements for fire risk management of these relatively small quantities of flammable liquid will be as per AS1940 (*Storage and handling of flammable and combustible liquids*), including:

- Bunding requirements will be per AS1940, i.e. 100% of the largest tank, with bunding design and construction.
- Fire protection (fire extinguishers, hose reel requirements, separation distances).
- Design of ventilation of any building (if applicable) will be as per AS1940 with regards to flammable vapours.
- Valving and piping associated with the storage.
- Control of ignition sources.

Provided the requirements from AS1940 are complied with, the probability of a fire involving the relatively small quantities of glycol, diesel and lube oil is minimal. A pool fire involving these materials is possible (just as for any storage of a flammable liquid). With the AS1940-requirements, the risk of a pool fire and a potential propagation to other areas is very low. The risk associated with these combustible liquids will not be discussed further.

A2.13 Prevention of Flooding of Site

Facilities will be designed and built in low flood risk areas and the site will be built up where required so as to achieve a site elevated above surrounding land to level above any local flood line.

Drainage system will be designed to shed water runoff to a lower point, to avoid water ponding on site.

Appendix 3

Consequence Assessment

Preliminary Hazard and Risk Assessment of Arrow

Energy's Surat Gas Project, QLD

Appendix 3 – Consequence Assessment

A set of representative incident scenarios was determined, based on the current and expected future design and layout of the facilities, applicable codes and standards, and good engineering practice. These scenarios include a range of the hazardous events that have some potential to occur in each area of the plant. In general, these events can be divided into the following categories:

- Moderate releases (punctures), characterised by a hole equivalent to 10% of the cross sectional surface area of the pipe diameter;
- Large releases (ruptures), characterised by a hole with a diameter equal to the pipe diameter or, for vessels and certain process equipment, a hole with a diameter equal to the diameter of the largest attached pipe;
- Massive failure of a vessel, characterised by a release over 10 minutes of the full contents of the vessel;
- Catastrophic failure of a vessel, characterised by an instantaneous release of its contents.

These categories follow the methodologies for QRAs in the *Purple Book* by the Netherlands Organisation for Applied Scientific Research *TNO*.

A3.1 Modelling Software

Consequence analysis was undertaken using the TNO Quantitative Risk Assessment program *Riskcurves* (version 7.6) and consequence modelling software program *Effects* (version 8.0). The TNO tools are internationally recognised by industry and government authorities.

The consequence models used within Riskcurves are well known and are fully documented in the TNO Yellow Book (Ref 22).

An appropriate release rate equation is selected based on the release situation and initial state of the material. The atmospheric dispersion model for lighter-than-air releases is used to model dispersion behaviour for natural gas.

A3.2 Evaluation Techniques

A3.2.1 Leak Rates

Riskcurves and Effects model release behaviour for compressed gas, liquid or 2-phase releases from vessels, pipelines or total vessel rupture. Input data includes the type of release, location of release with respect to vessel geometry, pipe lengths etc. and initial conditions of the fluid (i.e. before release).

The release rate is assumed to remain constant until isolation can be achieved - this is a conservative approach as in reality there will be pressure reduction and hence reduction in leak rate.

A3.2.2 Duration

The duration of a leak will depend on the hardware systems available to isolate the source of the leak, the nature of the leak itself and the training, procedures and management of the plant. While in some cases it may be argued that a leak will be isolated within one minute, the same leak under different circumstances may take 10 minutes to isolate. Under worst case conditions, such as where there are large quantities of materials between two isolating valves, the release may last even longer. In such cases, the release pressure and hence the release rate will decrease.

The approach used in this study for the failure scenarios identified is to assume the release continues until the inventory has been released, up to a maximum duration of one hour. This is a conservative assumption as the operators have the ability to isolate the leak using remote operated valves.

Where automatic response has been designed into the plant (e.g. in the form of process trips), such response has been taken into account, with the relevant probability of failure of the trip.

A3.2.3 Dispersion Distances

A gas released will disperse in the atmosphere. At concentrations between the upper flammable limit (UFL) and the lower flammable limit (LFL) methane (the main constituent of CSG) is flammable. The Riskcurves model is used to estimate the distance to which a release of methane will disperse to half the LFL for momentum driven (high pressure, high velocity releases). Feed rates for gas dispersion models are taken from gas release rates calculated by Effects.

The Effects consequence model is used to model the release of gas from a pressurized vessel or pipeline where the gas is emitted at high velocity.

The Effect does not appear to take account of the buoyancy of the gas plume. This may be applicable though conservative) for very large releases of methane, where Effect initially predicts a cooling of the gas during the release resulting in a denser than air gas. However, for smaller (more likely) releases this approach is highly conservative.

A3.2.4 Terrain Effects

Ground roughness effects the turbulent flow properties of wind, hence dispersion of a released material. Terrain effects are taken into account to some degree in dispersion modelling by use of a surface roughness length.

The roughness factor used for all release scenarios is described as *Low crops, occasional large objects* in the modelling software. This corresponds to a surface roughness factor of 0.1 m, appropriate to a plant located in a rural area, with some buildings, trees and fences in the vicinity, as well as some undulation of the surrounding land.

Please note that the TNO modelling software does not account for topographical changes in elevation within the dispersion analysis and will assume a constant surface roughness factor throughout the dispersion calculation.

A3.2.5 Time Periods

The time periods *Day* and *Night* are used and assumed to represent the periods 7.30 am-7.29 pm and 7.30pm-7.29 am, respectively (used for societal risk calculations).

A3.3 Heat Radiation and Explosion Overpressures

A3.3.1 Modelling Techniques - Theory

Heat Radiation

The effect or impact of heat radiation on people is shown in the Table below.

Table A3.1 - Effects of Heat Radiation

Radiant Heat Level (kW/m^2)	Physical Effect (effect depends on exposure duration)
1.2	Received from the sun at noon in summer
2.1	Minimum to cause pain after 1 minute
4.7	Will cause pain in 15-20 seconds and injury after 30 seconds' exposure
12.6	Significant chance of fatality for extended exposure High chance of injury
23	Likely fatality for extended exposure and chance of fatality for instantaneous (short) exposure
35	Significant chance of fatality for people exposed instantaneously

In Riskcurves, heat radiation effects are calculated based on flame surface emissive power (which is dependent on the quantity of material, its heat of combustion, flame dimensions and the fraction of heat radiated), as per the Yellow Book by TNO (in Ref 22). The heat flux at a particular distance from a fire is calculated using the view factor method. The view factor takes into account the distance from the flame to the target, the flame dimensions and the orientation angle between the flame and the target.
The effect of heat radiation on a person is calculated from the probit equation which relates to the probability of fatality to the thermal *dose* received (i.e. the combined heat and exposure time) though the following equations.

$$\text{Probit } Pr = -36.38 + 2.56\ \ln(tQ^{1.33})$$

With t = exposure time (sec) and Q = heat flux (W/m^2).

And with the relationship between the probit value and the probability of fatality is calculated as follows:

Probability of fatality = ——

Overpressure

The effect or impact of overpressure is shown in the table below.

Table A3.2 – Effect of Explosion Overpressure

Overpressure (kPa(g))	Physical Effect
3.5	90% glass breakage. No fatality, very low probability of injury
7	Damage to internal partitions & joinery 10% probability of injury, no fatality
14	Houses uninhabitable and badly cracked
21	Reinforced structures distort, storage tanks fail 20% chance of fatality to person in building
35	Houses uninhabitable, rail wagons & plant items overturned. Threshold of eardrum damage, 50% chance of fatality for a person in a building, 15% in the open
70	Complete demolition of houses Threshold of lung damage, 100% chance of fatality for a person in a building or in the open

In Riskcurves, the Multi Energy method is used to predict the overpressures from flammable gas explosions, as per the Yellow Book (Ref 22). The key feature of the Multi-Energy method is that the explosion is not primarily defined by the fuel air mixture but by the environment in which the vapour disperses.

Partial confinement is regarded as a major cause of vapour cloud explosion. Blast of substantial strength is not expected to occur in open areas. Strong blast is generated only in places characterized by partial confinement while other large parts of the cloud burn out without contributing to the blast effects. The vapour cloud explosion is not regarded as an entity but is defined as a number of sub-explosions corresponding to various sources of blast in the vapour cloud, i.e. each confined part of the cloud is calculated as a separate vapour cloud explosion.

The initial strength of the blast is variable, depending on the degree of confinement and on the reactivity of the gas. The initial strength is represented as a scale of 1 to 10 where 1 means slow deflagration and 10 means detonation. For explosions in process plant environments the initial strength is thought to lie between 4 to 7 on the scale.

A3.3.2 Calculated Fire Dimensions

Flame dimensions will vary depending on the wind weather conditions. *Riskcurves* calculates the flame dimensions for each wind weather category and incorporates these into the risk assessment together with their respective probability of occurrence.

A3.3.3Population Density

Societal risk assesses the risk of a hazardous event occurring in time and space with a human population. The population density of the surrounding area is entered into *Riskcurves*. As per the convention the population at the plant itself is set at zero.

A3.4 Consequence Calculations

The initial outflow rates estimated for natural gas releases are shown in Appendix 1. The results predict that the rate of decrease in outflow rate for a full bore rupture is dramatic with a drop to less than half of the initial flow within seconds and further rapid decay. However, the present QRA has assumed that the initial release rate remains until isolation can be achieved.

A3.5 Meteorological Data

Queensland is a subtropical region with high temperatures and high humidity. The weather has two distinct seasons, wet season and dry season. Gladstone enjoys subtropical climate and the region enjoys over 280 days of sunshine a year. The following meteorological data were used as input into the assessment:

- Average annual temperature (wet air) - 18.7^{o}C;
- The average annual barometric pressure - 1015.7 Pa(a);
- Solar radiation – 20.9MJ/m^2;
- Relative humidity is 70%.

The wind weather data used for the assessment is sourced for the Surat Gas Project development area is shown in Table A3.3 below.

Table A3.3 - Annual Wind Speed, Probability of Occurrence of Weather Category and Direction

Wind weather category	Rep. Wind Speed (m/s)	% Day	% Night	SSW	SWW	W	NWW	NNW	N	NNE	NE	E	SEE	SSE	S
B (unstable)	3.00	35.50	0.25	9.08	6.01	7.77	7.44	7.96	4.93	6.01	14.40	19.87	8.09	4.72	3.72
D (Neutral)	1.50	0.80	0.06	18.67	18.67	20.00	6.67	1.33	1.33	0.00	7.33	15.33	8.00	2.67	0.00
D (Neutral)	5.00	3.22	0.91	6.34	5.23	6.47	5.10	5.96	4.41	4.96	22.13	22.87	8.68	5.65	2.20
D (Neutral)	9.00	8.00	3.18	15.07	5.70	5.30	3.90	5.19	4.89	5.19	19.30	27.62	5.75	0.87	1.22
E (Stable)	5.00	0.67	15.92	9.71	2.95	2.78	0.89	2.04	5.42	11.35	27.30	29.60	5.04	0.93	1.99
F (Very Stable)	1.50	1.84	29.68	13.95	4.38	4.66	3.22	4.24	3.91	6.52	24.50	17.77	7.03	5.11	4.71

A3.6 Incident Scenarios

Incident scenarios and consequence calculations are included below.

The initial outflow rates estimated for gas using Effects (by TNO) releases are shown. The results predict that the rate of decrease in outflow rate for a full bore rupture is dramatic with a drop to less than half of the initial flow within seconds and further rapid decay. However, this assessment has assumed that the initial release rate remains until isolation can be achieved - this is a conservative approach.

The distance from the source of the release to the specified concentrations of the flammable cloud and heat radiation is also listed.

The scenarios listed below were entered as raw data into the *Riskcurves* program (by TNO).

Note that these values are included in this assessment for indicative purposes only as the computer modelling software *Riskcurves* was used to calculate the risk contours associated with the proposed development.

The initial outflow rates estimated for gas using Effects (by TNO) releases are shown in Table A3.4 onwards. The results predict that the rate of decrease in outflow rate for a full bore rupture is dramatic with a drop to less than half of the initial flow within seconds and further rapid decay. However, this assessment has assumed that the initial release rate remains until isolation can be achieved - this is a conservative approach.

The distance from the source of the release to the specified concentrations of the flammable cloud and heat radiation is also listed.

The scenarios listed below were entered as raw data into the *Riskcurves* program (by TNO).

Note that these values are included in this assessment for indicative purposes only as the computer modelling software *Riskcurves* was used to calculate the risk contours associated with the proposed development.

Table A3.4 – Consequence Modelling Results for Gas Wells

LEGEND

WLHDTUB	=	Gas line from well head within casing
CASING	=	Casing at well head
WHSDV	=	Gas line from well head to shutdown valve
HOSE1	=	Flexible line at well head
SDVWS	=	Line from the shut down valve to the water separator
SDVGAT	=	Line from the shutdown valve to the gathering line
HOSE2	=	Flexible line at entrance to gathering line
RLFVLV	=	Relief valve
SEPARA	=	Separator
WORKOVER	=	Workover initiated incident
SHINWHP	=	Shut in well head piping (incident during)
SHINCASE	=	Shut in well head casing (incident during)

EQUIPMENT	DIAM ORIF. metre	OUTFLOW kg/min	CLOUD (KG)	CLOUD (KG)	DISTANCE TO HEAT RADIATION (METRES)			FLAME LENGTH metre
			Wind weather stability *D4* Typical day	Wind weather stability *F2* Typical night	$22kW/m^2$	$12.5kW/m^2$	$4.7kW/m^2$	
WLHDTUB	0.073	0.77	10	14	14	17	18	12
WLHDTUB	0.025	0.09	<10	<10	3	6	12	7
WLHDTUB	0.013	0.02	<10	<10	3	3	4	3
WLHDTUB	0.003	0.001	<10	<10	<1	<1	<1	<1
WLHDTUB	0.013	0.02	<10	<10	3	3	4	3
CASING	0.186	4.89	50	330	26	30	40	26
CASING	0.025	0.09	<10	<10	3	6	12	10
CASING	0.013	0.02	<10	<10	3	3	4	3

EQUIPMENT	DIAM ORIF. metre	OUTFLOW kg/min	CLOUD (KG)	CLOUD (KG)	DISTANCE TO HEAT RADIATION (METRES)			FLAME LENGTH metre
			Wind weather stability *D4* Typical day	Wind weather stability *F2* Typical night	$22kW/m^2$	$12.5kW/m^2$	$4.7kW/m^2$	
CASING	0.003	0.001	<10	<10	<1	<1	<1	<1
CASING	0.013	0.02	<10	<10	1	2	2	3
WHSDV	0.080	0.77	<10	17	14	17	18	12
WHSDV	0.025	0.09	<10	<10	3	6	12	7
WHSDV	0.013	0.02	<10	<10	3	3	4	3
WHSDV	0.003	0.001	<10	<10	<1	<1	<1	<1
WHSDV	0.006	0.02	<10	<10	3	3	4	3
HOSE1	0.080	0.77	<10	17	14	17	18	12
HOSE1	0.025	0.09	<10	<10	3	6	12	7
HOSE1	0.013	0.02	<10	<10	3	3	4	3
HOSE1	0.003	0.001	<10	<10	<1	<1	<1	<1
HOSE1	0.006	0.02	<10	<10	3	3	4	3
SDVWS	0.080	0.39	<10	<10	5	10	15	10
SDVWS	0.025	0.05	<10	<10	4	5	5	4
SDVWS	0.013	0.01	<10	<10	<1	1	4	2
SDVWS	0.003	0.001	<10	<10	<1	<1	<1	<1
SDVWS	0.013	0.01	<10	<10	<1	1	4	2

EQUIPMENT	DIAM ORIF. metre	OUTFLOW kg/min	CLOUD (KG) Wind weather stability *D4* Typical day	CLOUD (KG) Wind weather stability *F2* Typical night	DISTANCE TO HEAT RADIATION (METRES) 22kW/m^2	12.5kW/m^2	4.7kW/m^2	FLAME LENGTH metre
SDVGAT	0.080	0.39	<10	<10	5	10	15	10
SDVGAT	0.025	0.05	<10	<10	4	5	5	4
SDVGAT	0.013	0.01	<10	<10	<1	1	4	2
SDVGAT	0.003	0.001	<10	<10	<1	<1	<1	<1
SDVGAT	0.006	0.01	<10	<10	<1	1	4	2
HOSE2	0.080	0.39	<10	<10	5	10	15	10
HOSE2	0.025	0.05	<10	<10	4	5	5	4
HOSE2	0.013	0.01	<10	<10	<1	1	4	2
HOSE2	0.003	0.001	<10	<10	<1	<1	<1	<1
HOSE2	0.006	0.01	<10	<10	<1	1	4	2
RLFVLV	0.080	1.44	<10	45	5	10	15	10
RLFVLV	0.025	0.16	<10	<10	4	5	5	4
RLFVLV	0.003	0.002	<10	<10	<1	1	4	2
SEPARA	cat rupture	0.39	<10	<10	-	-	-	-
SEPARA	0.050	0.15	<10	<10	6	7	10	6
SEPARA	0.023	0.05	<10	<10	4	4	5	4
SEPARA	0.011	0.01	<10	<10	<1	<1	2	<1
SEPARA	0.003	0.001	<10	<10	<1	<1	<1	<1

EQUIPMENT	DIAM ORIF. metre	OUTFLOW kg/min	CLOUD (KG)	CLOUD (KG)	DISTANCE TO HEAT RADIATION (METRES)			FLAME LENGTH metre
			Wind weather stability *D4* Typical day	Wind weather stability *F2* Typical night	$22kW/m^2$	$12.5kW/m^2$	$4.7kW/m^2$	
WORKOVER	0.073	0.77	<10	<10	14	17	18	12
SHINWHP	0.073	1.85	86	68	10	17	22	10
SHINWHP	0.025	0.22	<10	<10	2	4	12	3
SHINWHP	0.013	0.06	<10	<10	<1	5	8	3
SHINWHP	0.003	0.003	<10	<10	<1	<1	<1	<1
SHINWHP	0.013	0.06	<10	<10	<1	5	8	3
SHINCASE	0.186	12.17	17	1480	30	45	60	35
SHINCASE	0.025	0.22	<10	<10	3	6	10	6
SHINCASE	0.013	0.06	<10	<10	<1	<1	5	3
SHINCASE	0.003	0.003	<10	<10	<1	<1	<1	<1
SHINCASE	0.013	0.06	<10	<10	<1	<1	5	3

Table A3.5 – Consequence Modelling Results for Gathering Line

LEGEND

GATHSMALL	Small diam. gathering line (100mm)
GATHLARGE	Large diam. gathering line (630mm)

	EQUIPMENT	GAS PRES. kPa	DIAM ORIF. m	CROSS AREA m2	OUTFLOW kg/s	CLOUD (KG) D4	CLOUD (KG) F2	LENGTH LEL (M) D4	F2
LOW P	GATHSMALL	1.00E+05	0.100	7.85E-03	2.7	N/A	4	5	5
	GATHSMALL	1.00E+05	0.032	7.85E-04	0.2	N/A	N/A	3	3
	GATHSMALL	1.00E+05	0.020	3.14E-04	0.1	N/A	N/A	<1	<1
	GATHLARGE	1.00E+05	0.630	3.12E-01	99	1402	740	65	65
	GATHLARGE	1.00E+05	0.199	3.12E-02	8	N/A	23	20	20
	GATHLARGE	1.00E+05	0.020	3.14E-04	0.1	N/A	N/A	<1	<1
MED P	GATHSMALL	1.00E+06	0.100	7.85E-03	5.9	N/A	16	8	8
	GATHSMALL	1.00E+06	0.032	7.85E-04	0.3	N/A	N/A	2	2
	GATHSMALL	1.00E+06	0.020	3.14E-04	0.1	N/A	N/A	<1	<1
	GATHLARGE	1.00E+06	0.630	3.12E-01	421	1431	1865	190	190
	GATHLARGE	1.00E+06	0.199	3.12E-02	14.0	43	50	15	15
	GATHLARGE	1.00E+06	0.020	3.14E-04	0.1	N/A	N/A	3	3

	EQUIPMENT	LENGTH TO HEAD RADIATION (M)			TNT EQUIVALENT	DIST TO 70mbar
		22kW/m2	12.5kW.m2	4.7kW/m2	MASS (KG)	(M)
LOW P	GATHSMALL	4	6	7	N/A	N/A
	GATHSMALL	<1	7	6	N/A	N/A
	GATHSMALL	<1	5	6	N/A	N/A
	GATHLARGE	35	45	60	322	36
	GATHLARGE	25	35	47	10	36
	GATHLARGE	<1	5	6	N/A	N/A
MED P	GATHSMALL	4	10	15	7	25
	GATHSMALL	4	8	12	N/A	21
	GATHSMALL	<1	6	10	N/A	16
	GATHLARGE	75	100	140	811	35
	GATHLARGE	50	70	90	22	35
	GATHLARGE	<1	7	11	N/A	17

Table A3.6 – Consequence Modelling Results for Field Compression Facility

LEGENDS

BATCOM Line as it travels above ground (at the road way) to the inlet of the compr

COMMET Lines from the compressors to the metering skid

SEPARATOR Inlet separator (PV)

COMPSCREV Compressor (2 screw compressors online)

COMPRECIPI Compressor (2 reciprocating compressors online)

EQUIPMENT	GAS PRES. (Pa)	DIAM ORIF. (metres)	CROSS AREA (m2)	LEAK RATE (kg/s)	REPR. RELEASE DURATION (seconds)	D4 CLOUD (KG)	F2 CLOUD (KG)	HEAT RADIATION 22kW/m2	HEAT RADIATION 12.5kW/m2	HEAT RADIATION 4.7kW/m2
BATCOM	3.00E+04	1.50E-01	1.77E-02	3.6	1000	<10	<10	8	15	22
BATCOM	3.00E+04	4.74E-02	1.77E-03	0.60	1000	<10	<10	<1	5	25
COMMET	9.80E+06	1.50E-01	1.77E-02	116.0	1000	736	813	120	130	150
COMMET	9.80E+06	4.74E-02	1.77E-03	18.6	1000	67	68	50	60	70
COMPRESSOR	9.80E+06	2.00E-01	3.14E-02	116.0	1000	736	813	120	130	150
COMPRESSOR	9.80E+06	6.32E-02	3.14E-03	18.6	1000	67	68	50	60	70
SEPARATOR	3.00E+04	cat rupture	cat rupture	instantaneous	1000	178	200	110	90	140
SEPARATOR	3.00E+04	10min release	10min release	0.33	1000	178	200	110	90	140
SEPARATOR	3.00E+04	1.00E-02	7.85E-05	18.4	1000	178	200	110	90	140

EQUIPMENT	FLAME LENGTH (metres)	DISTANCE TO OVERPRESSURE (m)		DIST TO LFL (M)
		7kPa	14kPa	
BATCOM	14	N/A	N.A	5
BATCOM	6	N/A	N/A	1.5
COMMET	90	94	72	80
COMMET	50	54	31	18
COMPRESSOR	90	94	72	80
COMPRESSOR	50	54	31	18
SEPARATOR	150	78	45	10
SEPARATOR	150	78	45	<1
SEPARATOR	150	78	45	18

Table A3.7 – Consequence Modelling Results for Central Gas Processing Facility (and Integrated Processing Facility)

LEGENDS

BATCOM	Line as it travels above ground (at the road way) to the inlet of the compressors
COMMET	Lines from the compressors to the metering skid
SEPARATOR	Inlet separator (PV)
COMPSCREW	Compressor (9 screw compressors online)
COMPRECIPR	Compressor (3 reciprocating compressors online)
DISSC2	Discharge scrubber vessel
GLYCO2	Glycol contactor vessel

EQUIPMENT	DIAM ORIF. (m)	CROSS AREA (m^2)	LEAK RATE (kg/s)	D4 CLOUD (KG)	F2 CLOUD (KG)	DISTANCE TO HEAT RADIATION (m) 22Kw/M2	12.5Kw/M2	4.7Kw/M2	FLAME LENGTH (m)
BATCOM	1.50E-01	1.77E-02	0.52	<10	<10	8.00	15.00	22.00	14.00
BATCOM	4.74E-02	1.77E-03	0.11	<10	<10	<4	5.00	10.00	6.00
COMMET	1.50E-01	1.77E-02	117.15	457	467	110	140	150	90
COMMET	4.74E-02	1.77E-03	18.41	457	467	110	140	150	90
COMMET	1.50E-01	1.77E-02	117.15	1508	2674	110	140	150	90
COMMET	4.74E-02	1.77E-03	18.41	457	467	110	140	150	90
COMMET	1.50E-01	1.77E-02	117.15	6438	59829	110	140	150	90
COMMET	4.74E-02	1.77E-03	18.41	332	2903	50	60	70	40
COMPRESSOR	2.30E-02	4.15E-04	117.15	178	200	110	140	150	90
COMPRESSOR	1.10E-02	9.50E-05	18.41	178	200	110	140	150	90
COMPRESSOR	2.50E-03	4.91E-06	117.15	457	467	110	140	150	90
COMPRESSOR	7.91E-04	4.91E-07	18.41	457	467	50	60	70	40
SEPARATOR	cat rupture	cat rupture	instantaneous	178	200	110	140	150	90
SEPARATOR	10min release	10min release	0.33	178	200	110	140	150	90
SEPARATOR	1.00E-02	7.85E-05	18.41	178	200	110	140	150	90

EQUIPMENT	DIAM ORIF. (m)	CROSS AREA (m^2)	LEAK RATE (kg/s)	D4 CLOUD (KG)	F2 CLOUD (KG)	DISTANCE TO HEAT RADIATION (m) 22Kw/M2	12.5Kw/M2	4.7Kw/M2	FLAME LENGTH (m)
DISSC2	cat rupture	cat rupture	instantaneous	178	200	110	140	150	90
DISSC2	10min release	10min release	0.33	178	200	110	140	150	90
DISSC2	1.00E-02	7.85E-05	18.41	178	200	110	140	150	90
GLYCO2	cat rupture	cat rupture	instantaneous	178	200	110	140	150	90
GLYCO2	10min release	10min release	0.33	178	200	110	140	150	90
GLYCO2	1.00E-02	7.85E-05	18.41	178	200	110	140	150	90

Appendix 4

Frequency Assessment

Appendix 4 - Frequency Assessment

A4.1 Equipment failure frequency

The frequency of each postulated equipment failure was determined using the data in Table A4.1 below.

The failure rate for the gas wells are derived from the UK Health and Safety Executive *Offshore Hydrocarbon Release Statistics 2001, Offshore Technology Report, January 2002* (Ref 35), as used in the Department of Planning's[42] *Locational Guidelines - Development in the Vicinity of Operating Coal Seam Methane Wells*, May 2004 (Ref 6). These failure rates are summarised in the table below. The failure rate for the flexible lines on the gas wells is from the UK Health and Safety Executive database *FRED* (Ref 36).

The failure rates for the gathering lines are derived from the data provided by the Based on information from the US Dept of Transportation Office of Pipeline Safety.

The frequencies used for process plant (FCF and CGPF) are those in the database documented in the *Purple Book* by the Dutch TNO (the Netherlands Organisation for Applied Scientific Research) (Ref 37) and which is a worldwide recognised source of reference for quantitative risk assessments of potentially hazardous industry.

The TNO data does not include compressor failure and hence this data has been sourced from the International Association of Oil & Gas Producers (IAOGP) Risk Assessment Data Directory (Ref 38).

Table A4.1 - Equipment Failures and Associated Frequencies

Type of Failure	Failure Rate (per million per year)
GAS WELLS PIPING AND FLANGES/JOINTS	
3 mm hole	141 / m
13 mm hole	26 / m
25 mm hole	15 / m
Guillotine fracture (full bore) for pipe	20 / m
Flange failure all leak sizes (for pipe < 3") as 6mm leak size	43 / joint
(Screw-connection taken as 3xfailure rate for flange, as 6 mm leak size)	127 / joint
GAS WELLS RELIEF VALVES AND OTHER VALVES	
3 mm hole	152 / valve
25 mm hole	17 / valve
80 mm hole (rupture)	17 / valve
GAS WELLS PRESSURE VESSEL	
6 mm hole	24

[42] Then the Department of Infrastructure, Planning and Natural Resources

Table A4.1 - Equipment Failures and Associated Frequencies

Type of Failure	Failure Rate (per million per year)
13 mm hole	6
25 mm hole	3
50 mm hole	3
Catastrophic rupture	1
GAS WELLS FLEXIBLE LINES	
15 mm hole	2.8
Catastrophic rupture (basic facility)	40
GATHERING LINE	
<20 mm hole – pipeline	0.38 / m
<80 mm hole – pipeline	0.04 / m
Guillotine fracture (full bore)	0.014 / m
GATHERING LINE WITH CONCRETE SLAB	
<20 mm hole – pipeline	0.38 / m
<80 mm hole – pipeline	0.04 / m
Guillotine fracture (full bore) –	0.014 / m
COMPRESSOR STATION AND CGPF - ABOVE GROUND PIPE PIPELINES WITHIN FIXED PLANT	
Leak (outflow from leak with effective diameter of 10% of nominal diameter, a max. of 50 mm):	
< 75 mm	5 / m
> 75 mm but < 150 mm	2 / m
> 150 mm	0.5 / m
Guillotine fracture (full bore):	
< 75 mm	1 / m
> 75 mm but < 150 mm	0.3 / m
> 150 mm	0.1 / m
COMPRESSOR STATION AND CGPF - PRESSURE VESSELS	
Instantaneous release of the complete inventory	0.5
Continuous release of the complete inventory in 10 min at a constant rate of release	0.5
Continuous release from a hole with an effective diameter of 10 mm	10

Table A4.1 - Equipment Failures and Associated Frequencies

Type of Failure	Failure Rate (per million per year)
COMPRESSOR STATION AND CGPF - PRESSURE PROCESS	
Instantaneous release of the complete inventory	5
Continuous release of the complete inventory in 10 min at a constant rate of release	5
Continuous release from a hole with an effective diameter of 10 mm	100
COMPRESSOR LEAK	
Rupture	480
10% leak	3000

In the TNO methodology, failures of flanges are assumed to be included in the failure frequency of the pipeline; for that reason, the minimum length of a pipe is set at 10 metres.

For below ground pipelines the European Gas pipeline Incident data Group (EGIG), (Ref 27) provide an estimate as to the cause of the initial leak (assumed in this QRA to be applicable for all sizes of leak):

· External interference (damage caused by a third party) – 52%;

· Corrosion – 17%;

· Construction defect/material failure – 18%;

· Hot-tap made by error – 10%;

· Ground movement – 0.1%;

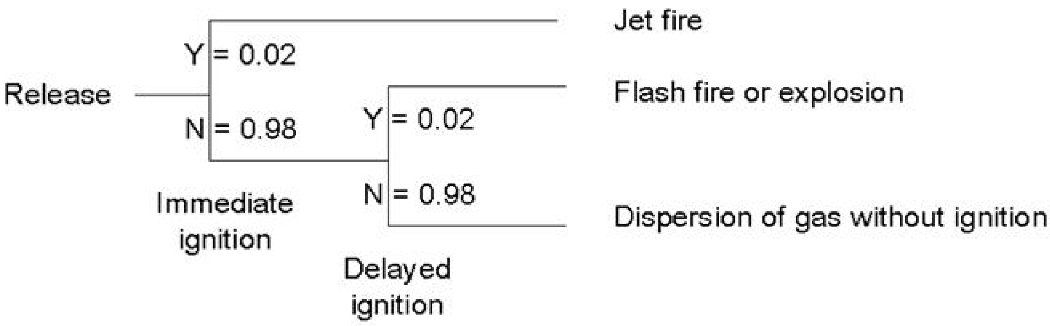
· Other and unknown causes - 2.5%.

Putting a concrete slab on top of a below ground pipeline is assumed to reduce the likelihood of damage to the pipeline by third party interference by 90%. Seeing this type of damage is responsible for about 52% of the incidents the leak frequency of the below ground pipeline can be estimated.

A4.2 Ignition Probability

The probability of ignition in case of a leak and the probability of a jet fire or a flash fire are as per the work by the Department for the *Locational Guidelines Development in the Vicinity of Operating Coal Seam Methane Wells* (Ref 6), as shown in Figure A4.1 below. These probabilities were developed by the Department to determine the likelihood of a flammable event following a release of gas from gas well installations located within a number of different types of development (open space, business, residential and sensitive development), and for the types of ignition sources which may be encountered within these developments.

Figure A4.1 – Ignition Probabilities



TNO's *The Purple Book* gives the probabilities for ignition for plants, such as the FCFs, CGPF and IPFs, as presented in Table A4.2 below. The probability increases as a function of the size of the release. For the smallest releases the ignition probability may be as low as 1-2%. Methane is considered to be of *low* reactivity, with correspondingly lower ignition probability.

Table A4.2 – Probability of Ignition

Release Rate for Continuous Source	Mass released for Instantaneous Source	On-plant Low Reactivity (Natural gas)
<10 kg/s	<1000 kg	0.02
10-100 kg/s	1000-10,000 kg	0.04
>100 kg/s	>10,000 kg	0.09

The probability of an explosion is virtually zero for a natural gas leak out in the open, such as for the gas wells and the gathering line. In this case, all delayed ignition cases are assumed to result in a flash fire. This is consistent with the approach taken in the NSW Department of Planning Locational Guidelines (Ref 6).

The probability of an explosion for the fixed plant (where there may be some confinement) is taken as 10% of the total delayed ignition case, with flash fires accounting for the other 90% of cases.

A4.3 Likelihood of Release Scenarios and Flammable Outcome

The frequency of outcome of each individual incident scenario is listed in Tables A4.2 (wells), A4.3 (gathering line), A4.4 (FCF) and A4.5 (CGPF/IPF) below.

Table A4.2 – Likelihood and Frequency Data for Incident Scenarios, Gas Wells

LEGEND

WLHDTUB	=	Gas line from well head within casing
CASING	=	Casing at well head
WHSDV	=	Gas line from well head to shutdown valve
HOSE1	=	Flexible line at well head
SDVWS	=	Line from the shut down valve to the water separator
SDVGAT	=	Line from the shutdown valve to the gathering line
HOSE2	=	Flexible line at entrance to gathering line
RLFVLV	=	Relief valve
SEPARA	=	Separator
WORKOVER	=	Workover initiated incident
SHINWHP	=	Shut in well head piping (incident during)
SHINCASE	=	Shut in well head casing (incident during)

EQUIPMENT	PIPE LENGTH metres	#JOINTS	LEAK FREQ. t/yr	JET FIRE FREQ. t/yr	FLASH FREQ. t/yr	EXPLOSION FREQ. t/yr
WLHDTUB	0.9	0	1.83E-05	3.66E-07	2.93E-07	2.93E-08
WLHDTUB	0.9	0	1.33E-05	2.66E-07	2.13E-07	2.13E-08
WLHDTUB	0.9	0	2.33E-05	4.66E-07	3.73E-07	3.73E-08
WLHDTUB	0.9	0	1.27E-04	2.53E-06	2.02E-06	2.02E-07
WLHDTUB	0.9	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CASING	0.1	0	2.04E-06	4.07E-08	3.26E-08	3.26E-09
CASING	0.1	0	1.48E-06	2.96E-08	2.37E-08	2.37E-09
CASING	0.1	0	2.59E-06	5.18E-08	4.14E-08	4.14E-09
CASING	0.1	0	1.41E-05	2.81E-07	2.25E-07	2.25E-08
CASING	0.1	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00

EQUIPMENT	PIPE LENGTH metres	#JOINTS	LEAK FREQ. t/yr	JET FIRE FREQ. t/yr	FLASH FREQ. t/yr	EXPLOSION FREQ. t/yr
WHSDV	5	4	1.02E-04	2.04E-06	1.63E-06	1.63E-07
WHSDV	5	4	7.40E-05	1.48E-06	1.18E-06	1.18E-07
WHSDV	5	0	1.30E-04	2.59E-06	2.07E-06	2.07E-07
WHSDV	5	2	7.03E-04	1.41E-05	1.12E-05	1.12E-06
WHSDV	5	2	2.55E-04	5.10E-06	4.08E-06	4.08E-07
HOSE1	1	2	4.00E-05	8.00E-07	6.40E-07	6.40E-08
HOSE1	1	2	2.80E-06	5.60E-08	4.48E-08	4.48E-09
SDVWS	1.5	5	1.53E-06	1.53E-09	2.44E-08	2.44E-09
SDVWS	1.5	5	1.11E-06	1.11E-09	1.78E-08	1.78E-09
SDVWS	1.5	2	3.89E-05	3.89E-08	6.22E-07	6.22E-08
SDVWS	1.5	5	2.11E-04	2.11E-07	3.37E-06	3.37E-07
SDVWS	1.5	5	6.37E-04	6.37E-07	1.02E-05	1.02E-06
SDVGAT	5	8	5.09E-06	1.02E-07	8.14E-08	8.14E-09
SDVGAT	5	8	3.70E-06	7.40E-08	5.92E-08	5.92E-09
SDVGAT	5	5	1.30E-04	2.59E-06	2.07E-06	2.07E-07
SDVGAT	5	8	7.03E-04	1.41E-05	1.12E-05	1.12E-06
SDVGAT	5	8	1.02E-03	2.04E-05	1.63E-05	1.63E-06
HOSE2	1	2	4.00E-05	8.00E-07	6.40E-07	6.40E-08
HOSE2	1	2	2.80E-06	5.60E-08	4.48E-08	4.48E-09
RLFVLV	0	0	8.33E-07	1.67E-08	1.33E-08	1.33E-09
RLFVLV	0	0	8.33E-07	1.67E-08	1.33E-08	1.33E-09
RLFVLV	0	0	1.52E-04	3.03E-06	2.43E-06	2.43E-07
SEPARA	0	0	5.00E-08	1.00E-09	8.00E-10	8.00E-11
SEPARA	0	0	1.50E-07	3.00E-09	2.40E-09	2.40E-10
SEPARA	0	0	1.50E-07	3.00E-09	2.40E-09	2.40E-10

EQUIPMENT	PIPE LENGTH metres	#JOINTS	LEAK FREQ. t/yr	JET FIRE FREQ. t/yr	FLASH FREQ. t/yr	EXPLOSION FREQ. t/yr
SEPARA	0	0	6.00E-06	1.20E-07	9.60E-08	9.60E-09
SEPARA	0	0	2.40E-05	4.80E-07	3.84E-07	3.84E-08
WORKOVER	0	0	4.98E-07	9.97E-09	7.97E-09	7.97E-10
SHINWHP	0.9	0	5.02E-07	1.00E-08	8.03E-09	8.03E-10
SHINWHP	0.9	0	3.65E-07	7.30E-09	5.84E-09	5.84E-10
SHINWHP	0.9	0	6.39E-07	1.28E-08	1.02E-08	1.02E-09
SHINWHP	0.9	0	9.50E-08	1.90E-09	1.52E-09	1.52E-10
SHINWHP	0.9	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SHINCASE	0.1	0	5.58E-08	1.12E-09	8.92E-10	8.92E-11
SHINCASE	0.1	0	4.05E-08	8.11E-10	6.49E-10	6.49E-11
SHINCASE	0.1	0	7.10E-08	1.42E-09	1.14E-09	1.14E-10
SHINCASE	0.1	0	3.85E-07	7.70E-09	6.16E-09	6.16E-10
SHINCASE	0.1	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table A4.3 – Likelihood and Frequency Data for Incident Scenarios, Gathering Line

LEGEND

GATHSMALL	Small diam gathering line (80mm)
GATHLARGE	Large diam gathering line (160mm)

EQUIPMENT	LEAK FREQ. t/km/yr	JET FIRE FREQ. t/km/yr	FLASH FREQ. t/km/yr	EXPL FREQ. t/km/yr
GATHSMALL	1.40E-05	2.80E-07	2.24E-07	2.24E-08
GATHSMALL	4.00E-05	8.00E-07	6.40E-07	6.40E-08
GATHSMALL	3.80E-04	7.60E-06	6.08E-06	6.08E-07
GATHLARGE	1.40E-05	2.80E-07	2.24E-07	2.24E-08
GATHLARGE	4.00E-05	8.00E-07	6.40E-07	6.40E-08
GATHLARGE	3.80E-04	7.60E-06	6.08E-06	6.08E-07

Table A4.4 – Likelihood and Frequency Data for Incident Scenarios, FCF

LEGENDS

BATCOM	Line as it travels above ground (at the road way) to the inlet of the compressors
COMMET	Lines from the compressors to the metering skid
SEPARATOR	Inlet separator (PV)
COMPSCREV	Compressor (2 screw compressors online)
COMPRECIPI	Compressor (2 reciprocating compressors online)

EQUIPMENT	LENGTH (m)	#JOINTS	LEAK FREQ. (t/yr)	JET FIRE FREQ. (t/yr)	FLASH FIRE FREQ. (t/yr)	EXPL. FREQ. (t/yr)
BATCOM	80	10	8.00E-06	1.60E-07	1.41E-07	1.57E-08
BATCOM	80	10	4.00E-05	8.00E-07	7.06E-07	7.84E-08
COMMET	30	20	3.00E-05	6.00E-07	5.29E-07	5.88E-08
COMMET	30	20	1.50E-04	3.00E-06	2.65E-06	2.94E-07
COMPRESSOR	30	20	9.60E-05	1.92E-06	1.69E-06	1.88E-07
COMPRESSOR	30	20	6.00E-04	1.20E-05	1.06E-05	1.18E-06
SEPARATOR	0	0	5.00E-07	1.00E-08	8.82E-09	9.80E-10
SEPARATOR	0	0	5.00E-07	1.00E-08	8.82E-09	9.80E-10
SEPARATOR	0	0	1.00E-05	2.00E-07	1.76E-07	1.96E-08

Table A4.5 – Likelihood and Frequency Data for Incident Scenarios, CGPF and IPF

LEGENDS

BATCOM	Line as it travels above ground (at the road way) to the inlet of the compressors
COMMET	Lines from the compressors to the metering skid
SEPARATOR	Inlet separator (PV)
COMPSCREW	Compressor (9 screw compressors online)
COMPRECIPR	Compressor (3 reciprocating compressors online)
DISSC2	Discharge scrubber vessel
GLYCO2	Glycol contactor vessel

EQUIPMENT	LENGTH	#JOINTS	LEAK FREQ.	FLASH FIRE FREQ.	EXPL. FREQ.
BATCOM	150	10	7.50E-07	1.20E-08	1.20E-09
BATCOM	150	10	3.75E-06	6.00E-08	6.00E-09
COMMET	300	20	9.00E-05	1.44E-06	1.44E-07
COMMET	300	20	1.50E-03	2.40E-05	2.40E-06
COMMET	300	20	1.50E-05	2.40E-07	2.40E-08
COMMET	300	20	7.50E-05	1.20E-06	1.20E-07
COMMET	300	20	7.50E-07	1.20E-08	1.20E-09
COMMET	300	20	3.75E-06	6.00E-08	6.00E-09
COMPRESSOR	300	20	3.60E-03	5.76E-05	5.76E-06
COMPRESSOR	300	20	1.80E-02	2.88E-04	2.88E-05
COMPRESSOR	300	20	1.80E-04	2.88E-06	2.88E-07
COMPRESSOR	300	20	9.00E-04	1.44E-05	1.44E-06
SEPARATOR	0	0	5.00E-07	8.00E-09	8.00E-10
SEPARATOR	0	0	5.00E-07	8.00E-09	8.00E-10
SEPARATOR	0	0	1.00E-05	1.60E-07	1.60E-08
DISSC2	0	0	5.00E-07	8.00E-09	8.00E-10

EQUIPMENT	LENGTH	#JOINTS	LEAK FREQ.	FLASH FIRE FREQ.	EXPL. FREQ.
DISSC2	0	0	5.00E-07	8.00E-09	8.00E-10
DISSC2	0	0	1.00E-05	1.60E-07	1.60E-08
GLYCO2	0	0	5.00E-07	8.00E-09	8.00E-10
GLYCO2	0	0	5.00E-07	8.00E-09	8.00E-10
GLYCO2	0	0	1.00E-05	1.60E-07	1.60E-08

A4.4 Failure of automatic protection

The following estimates of probabilities have been used as a guide for the purposes of determining the reliability of the automatic protection (Ref 39).

Table A4.6 – Safety Integrity Levels

Safety Integrity Level (SIL)	Low Demand Mode of Operation (probability of failure to perform as intended on demand)
4	>=10^{-5} to < 10^{-4}
3	>=10^{-4} to < 10^{-3}
2	>=10^{-3} to < 10^{-2}
1	>=10^{-2} to < 10^{-1}

The protective systems will be designed to SIL 1 requirements. Table A4.6 shows the probability of failure used for the automatic protective systems of the wells.

Table A4.7 - Probability of Failure of Automatic Protection

Safety Integrity Level (SIL)	Low Demand Mode of Operation (probability of failure to perform as intended on demand)
High pressure on the well (PSH)	0.05
Low pressure on the well (PLH)	0.05
High flow of gas through the metre run (FSH)	0.05
Low flow of gas through the metre run (FSL)	0.05
Fusible loop	0.05

A4.5 Risk Matrix

The risk matrix used for the qualitative hazard and risk assessment is provided below:

		Likelihood				
		Rare or practically impossible	Unlikely or uncommon	Possible, has occurred in the past but not common	Likely, has occurred in recent history	Almost certain or common
Consequence		**Rare**	**Unlikely**	**Possible**	**Likely**	**Almost certain**
Widespread, serious long-term effect	**Severe**	Medium	High	High	Very high	Very high
Wider spread, moderate to long-term effect	**Major**	Medium	Medium	High	High	Very high
Localised, short-term to moderate effect	**Moderate**	Low	Medium	Medium	Medium	High
Localised short-term effect	**Minor**	Very low	Low	Low	Medium	Medium
No impact or no lasting effect	**Negligible**	Very low	Very low	Low	Low	Medium

10 REFERENCES

1 *Terms of reference for the Arrow Energy Surat Gas Project Environmental Impact Statement (EIS)*, State of Queensland, Department of Environment and Resource Management, September 2010

2 *Environmental Impact Statement, Sales Gas Pipeline*, RPS, July 2009

3 ISO31000:2009 - *Risk management - Principles and guidelines*, November 2009

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