REVISED PRELIMINARY HAZARD ANALYSIS, ALERATIONS AND ADDITIONS TO AN EXISTING CARBON DIOXIDE PLANT, SUPAGAS (SHOALHAVEN STARCHES SITE), BOMADERRY, NSW

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Rev	Date	Description	Reviewed By
A	26/9/17	Draft for Comment	Supagas
B	10/12/17	Final Issue	Supagas
C	22/5/21	Draft - Updated with 2 New Tanks	Supagas
D	29/5/21	Final Issue	Supagas
E	11/2/25	Second CO2 Plant Added	Supagas
F	27/2/25	Comments on Rev E Included	Supagas
G	1/5/25	Plant Rates Revised. Supply CO2 pipe release rate revised to 1.9 kg/s	Supagas
H	13/5/25	Executive Summary and Section 1 Updated	Supagas

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EXECUTIVE SUMMARY

Supagas own and operate a 90 TPD carbon dioxide (CO2) plant at Bomaderry, NSW. Supagas propose to undertake alterations and additions to this existing carbon dioxide plant at the same site. This plant is proposed to increase production by 75 TPD CO2 bringing the total capacity of the plant to 165 TPD.

The plant is located on the Shoalhaven Starches site, i.e. adjacent to the former Dairy Farmers factory that now belongs to the Manildra Group of companies and which Shoalhaven Starches forms part. The site is located at 220 Bolong Road, Bomaderry.

As part of the project requirements, a revised Preliminary Hazard Analysis is required. This report details the results from the analysis.

The risks associated with the modified Supagas carbon dioxide plant at Bomaderry have been assessed and compared against the DoP risk criteria.

The results are as follows and show compliance with all risk criteria.

Description	Risk Criteria	Risk Acceptable?
Fatality risk to sensitive uses, including hospitals, schools, aged care	0.5×10^{-6} per year	Y
Fatality risk to residential and hotels	1×10^{-6} per year	Y
Fatality risk to commercial areas, including offices, retail centres, warehouses	5×10^{-6} per year	Y
Fatality risk to sporting complexes and active open spaces	10×10^{-6} per year	Y
Fatality risk to be contained within the boundary of an industrial site	50×10^{-6} per year	Y
Injury risk – incident heat flux radiation at residential areas should not exceed 4.7 kW/m^2 at frequencies of more than 50 chances in a million per year or incident explosion overpressure at residential areas should not exceed 7 kPa at frequencies of more than 50 chances in a million per year	50×10^{-6} per year	Y
Toxic exposure - Toxic concentrations in residential areas which would be seriously injurious to sensitive members of the community following a relatively short period of exposure	10×10^{-6} per year	Y
Toxic exposure - Toxic concentrations in residential areas which should cause irritation to eyes or throat, coughing or other acute physiological responses in sensitive members of the community	50×10^{-6} per year	Y

Description	Risk Criteria	Risk Acceptable?
Propagation due to Fire and Explosion – exceed radiant heat levels of 23 kW/m^2 or explosion overpressures of 14 kPa in adjacent industrial facilities	50×10^{-6} per year	Y

Societal risk, area cumulative risk, propagation risk, transport risk and environmental risk are also concluded to be acceptable. The primary reasons for the low risk levels from the site are the separation distances between the hazards to the nearest place of residence and that high levels of carbon dioxide are required to cause fatality.

As the proposed alterations and additions to the existing carbon dioxide plant involve plant and equipment that are very similar in design to the existing plant and that the proposed modifications have already been reviewed using the HAZOP technique then there are no further recommendations made in this study.

GLOSSARY

AEGL	Acute Exposure Guideline Levels
AS	Australian Standard
CATOX	Catalytic Oxidation
CCPS	Centre for Chemical Process Safety
CCTV	Closed Circuit Television
CO_2	Carbon Dioxide
DG	Dangerous Good
DoP	NSW Department of Planning
ERPG	Emergency Response Planning Guidelines
HAZOP	Hazard and Operability Study
HIPAP	Hazardous Industry Planning Advisory Paper
HSE	Health and Safety Executive (UK)
IDLH	Immediately Dangerous to Life and Health
LPM	Litres Per Minute
NOx	Nitrogen Oxides
PHA	Preliminary Hazard Analysis
ppm	Parts Per Million
QRA	Quantitative Risk Analysis
SEPP	State Environmental Planning Policy
SFARP	So Far As Reasonably Practicable
SLOT	Specified Level of Toxicity
STEL	Short Term Exposure Limit
TPD	Tonnes Per Day
TWA	Time Weighted Average
VIE	Vacuum Insulated Expander

REPORT

1 INTRODUCTION

1.1 BACKGROUND

Supagas own and operate a 90 TPD carbon dioxide (CO2) plant at Bomaderry, NSW. Supagas propose to undertake alterations and additions to this existing carbon dioxide plant at the same site. This plant is proposed to increase production by 75 TPD CO2 bringing the total capacity of the plant to 165 TPD.

The plant is located on the Shoalhaven Starches site, i.e. adjacent to the former Dairy Farmers factory that now belongs to the Manildra Group of companies and which Shoalhaven Starches forms part. The site is located at 220 Bolong Road, Bomaderry.

The carbon dioxide feed to the plant is from the fermentation process on the Shoalhaven Starches site. The carbon dioxide is purified and liquefied in the existing plant to food grade quality for the food and beverage market. The second plant is proposed to produce the same grade carbon dioxide.

The product liquid carbon dioxide is currently stored in four tanks:

- A 100 te insulated pressure vessel;
- A 200 te tank that has a stainless steel inner tank and a low temperature carbon steel outer tank;
- Two 150 te tanks that are similar in design to the 200 te tank, i.e. an inner and outer tank.

As part of the Project requirements, a revised Preliminary Hazard Analysis (PHA) is required. Supagas have requested that Pinnacle Risk Management prepare the revised PHA. The original approved PHA was issued in 2017 (Ref 1). A revised PHA that included the two 150 te tanks was issued in 2021 (Ref 2).

This revised PHA has been prepared in accordance with the guidelines published by the Department of Planning (DoP) Hazardous Industry Planning Advisory Paper (HIPAP) No 6 (Ref 3).

1.2 OBJECTIVES

The main aims of this revised PHA study are to:

- Identify the credible, potential hazardous events associated with the carbon dioxide facility including the second carbon dioxide plant;
- Evaluate the level of risk associated with the identified potential hazardous events to surrounding land users and compare the calculated risk levels with the risk criteria published by the DoP in HIPAP No 4 (Ref 4);
- Review the adequacy of the proposed safeguards to prevent and mitigate the potential hazardous events; and
- Where necessary, submit recommendations to Supagas to ensure that the proposed facility, including the second carbon dioxide plant, are operated and maintained at acceptable levels of process safety and effective safety management systems are used.

1.3 SCOPE

This revised PHA assesses the credible, potential hazardous events and corresponding risks associated with the modified Supagas carbon dioxide facility at Bomaderry with the potential for off-site impacts only.

Off-site transport risks were separately assessed as part of this Project's environmental assessments. The transport of the main hazardous materials, e.g. carbon dioxide, are included in this PHA.

1.4 METHODOLOGY

In accordance with the approach recommended by the DoP in HIPAP 6 (Ref 3) the underlying methodology of the PHA is risk-based, that is, the risk of a particular potentially hazardous event is assessed as the outcome of its consequences and likelihood.

This revised PHA has been conducted as follows:

- Initially, the facility, the location and the proposed modifications were reviewed to identify credible, potential hazardous events, their causes and consequences. Proposed safeguards were also included in this review;
- The consequences of the potential hazardous events that could have off-site impact were estimated;
- Where the consequential impacts can exceed the criteria in HIPAP 4 (Ref 4) then the likelihood and hence risk were estimated;
- Included in the analysis is the risk of propagation within the site; and

- Assess the risk levels to check if they are within the HIPAP 4 criteria (Ref 4).

1.5 RISK CRITERIA

The assessment of risks to both the public as well as to operating personnel from a potentially hazardous development requires the application of the basic steps outlined above. As per Applying SEPP 33 (Ref 5) and HIPAP 6 (Ref 3), the chosen analysis technique should be commensurate with the nature of the risks involved.

The typical risk analysis methodology attempts to take account of all credible hazardous situations that may arise from the operation of processing plants etc. Specific incidents, identified by a variety of techniques, are assessed in terms of consequences and likelihood.

Having assembled data on the credible incidents, risk analysis requires the following general approach for individual incidents (which are then summated for all potential recognised incidents to get cumulative risk):

Risk = Likelihood x Consequence

For QRA and hazard analysis, the consequences of an incident are calculated using standard correlations and probit-type methods which assess the effect of fire radiation, explosion overpressure and toxicity to an individual, depending on the type of hazard.

In this PHA, however, the approach adopted to assess the risk of the identified hazardous events is scenario-based risk assessment. The reason for this approach is the limited hazardous events with the potential for off-site harm, i.e. there are generous separation distances involved to sensitive receptors.

Therefore, appropriate analysis of credible scenarios is performed in this PHA. Typically, the consequences of the potential events with off-site impact are assessed first. For the events which do not contribute to off-site risk, as determined by the risk criteria in HIPAP No. 4 (Ref 4), then no further risk analysis is warranted. When the consequence of an event does have the potential to impact people off-site, the likelihood and hence risk is then analysed as required.

The NSW DoP risk criteria applying to developments are summarised in Table 1 (from Ref 4).

Table 1 - Risk Criteria, New Plants

Description	Risk Criteria
Fatality risk to sensitive uses, including hospitals, schools, aged care	0.5×10^{-6} per year
Fatality risk to residential and hotels	1×10^{-6} per year
Fatality risk to commercial areas, including offices, retail centres, warehouses	5×10^{-6} per year
Fatality risk to sporting complexes and active open spaces	10×10^{-6} per year
Fatality risk to be contained within the boundary of an industrial site	50×10^{-6} per year
Injury risk – incident heat flux radiation at residential areas should not exceed 4.7 kW/m^2 at frequencies of more than 50 chances in a million per year or incident explosion overpressure at residential areas should not exceed 7 kPa at frequencies of more than 50 chances in a million per year	50×10^{-6} per year
Toxic exposure - Toxic concentrations in residential areas which would be seriously injurious to sensitive members of the community following a relatively short period of exposure	10×10^{-6} per year
Toxic exposure - Toxic concentrations in residential areas which should cause irritation to eyes or throat, coughing or other acute physiological responses in sensitive members of the community	50×10^{-6} per year
Propagation due to Fire and Explosion – exceed radiant heat levels of 23 kW/m^2 or explosion overpressures of 14 kPa in adjacent industrial facilities	50×10^{-6} per year

2 SITE DESCRIPTION

The works associated with this modification application are all located at 220 Bolong Road, Bomaderry (Lot 143 DP 1069758) on the former Dairy Farmers' factory site (see Figure 1). This parcel of land comprises an area of 5.777 ha.

The subject site contains a factory complex previously occupied by the Dairy Farmers dairy factory. The Manildra Group of Companies now own this land.

The existing carbon dioxide plant has been established in accordance with Mod 15 adjacent to the former Dairy Farmers' factory on land located between the eastern property boundary and the paved truck circulation area which adjoins the eastern side of the former Dairy Farmers building.

The town of Bomaderry is located approximately 1.1 km to the west of the carbon dioxide plant site and the Nowra urban area is situated 2.1 km to the south west of the site. The suburb Terara is situated approximately 1.3 km to the south of the site across the Shoalhaven River. Pig Island is situated between the factory site and the village of Terara and is currently used for cattle grazing.

There are a number of industrial land uses, which have developed on the strip of land between Bolong Road and the Shoalhaven River. Industrial activities include a metal fabrication factory, the Shoalhaven Starches site, Shoalhaven Dairy Co-op (formerly Australian Co-operative Foods Ltd – now owned by the Manildra Group) and the Shoalhaven Paper Mill (also now owned by the Manildra Group). The nearest industrial neighbour to the proposed carbon dioxide plant is IMEEC (electrical contractors) immediately to the east.

Security of the site is achieved by a number of means. This includes site personnel and security patrols by an external security company (this includes weekends and night patrols). The site operates 7 days per week (24 hours per day). Also, the site is fully fenced and non-operating gates are locked. Security cameras are installed for staff to view visitors and site activities.

There are normally two people on site during standard business hours. Outside of standard business hours the plant is monitored via remote login as well as a remote control room.

The main natural hazard for the site is flooding. No other significant external events are considered high risk for this site.

Location and layout drawings showing the site and the proposed second carbon dioxide plant are shown in Figure 2 and Figure 3.

Figure 1 – Shoalhaven Starches Location

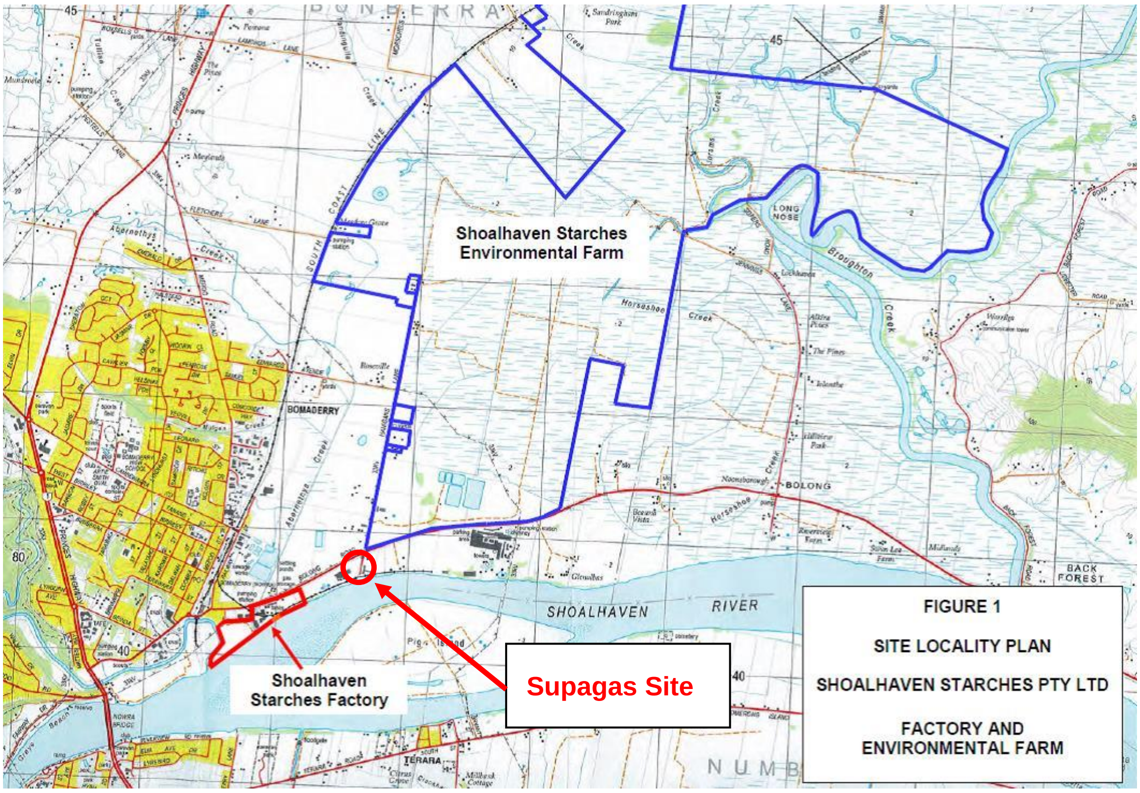
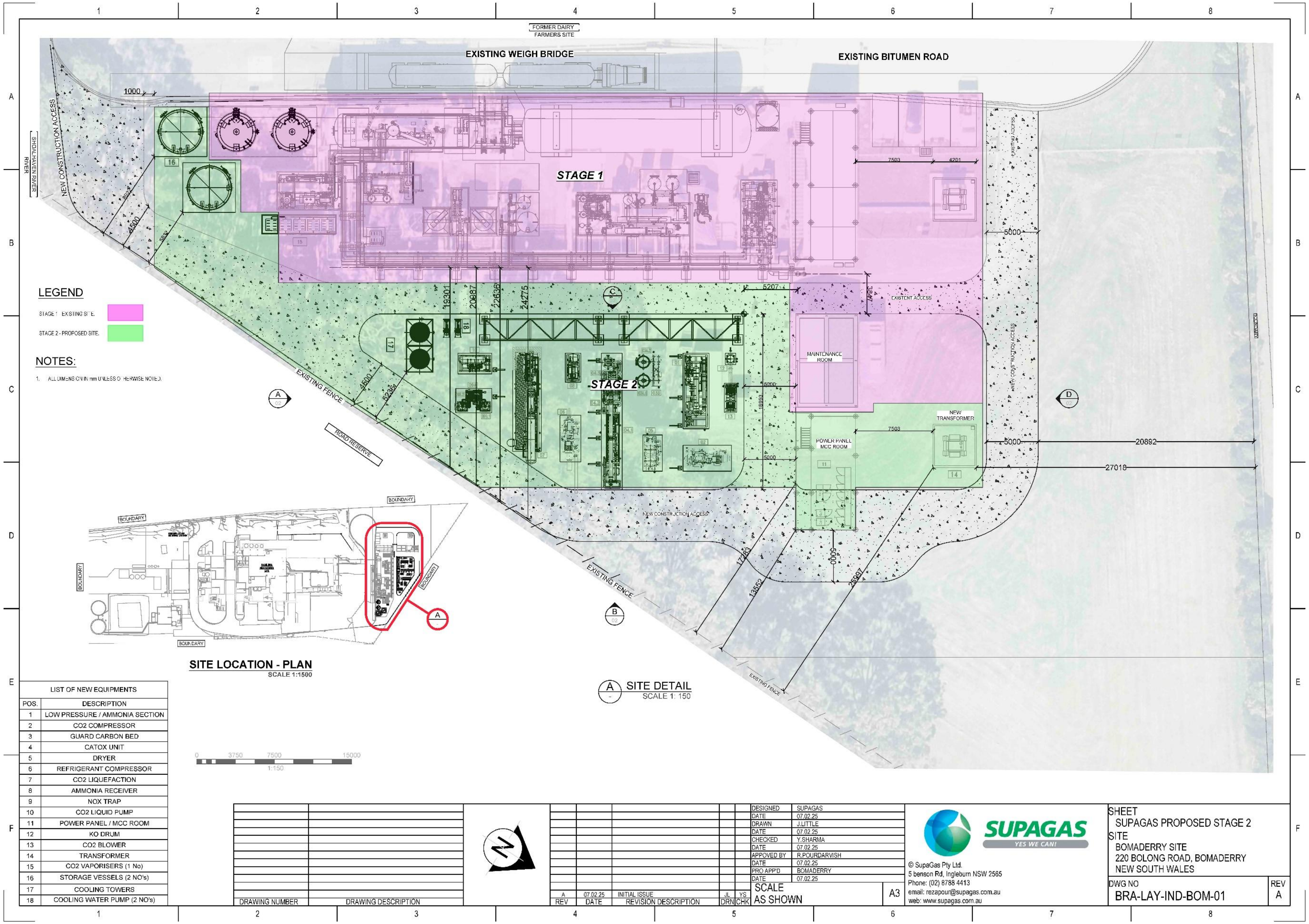


Figure 2 – Carbon Dioxide Plants Location

Source: Google Maps

Figure 3 – Plant Layout with the Proposed Second Carbon Dioxide Plant



LIST OF NEW EQUIPMENTS

POS.	DESCRIPTION
1	LOW PRESSURE / AMMONIA SECTION
2	CO2 COMPRESSOR
3	GUARD CARBON BED
4	CATOX UNIT
5	DRYER
6	REFRIGERANT COMPRESSOR
7	CO2 LIQUEFACTION
8	AMMONIA RECEIVER
9	NOX TRAP
10	CO2 LIQUID PUMP
11	POWER PANEL / MCC ROOM
12	KO DRUM
13	CO2 BLOWER
14	TRANSFORMER
15	CO2 VAPORISERS (1 No)
16	STORAGE VESSELS (2 NO's)
17	COOLING TOWERS
18	COOLING WATER PUMP (2 NO's)

3 PROCESS DESCRIPTION

3.1 EXISTING CARBON DIOXIDE PLANT

Supagas currently takes carbon dioxide with a purity of approximately 92 % from the Shoalhaven Starches fermentation system and processes this gas into food grade carbon dioxide (>99.99% purity) suitable for food and hospitality markets around Australia.

The existing plant has a capacity of 90 tonne per day.

The plant feed stream has the following approximate composition:

Carbon dioxide	91.7 vol%;
Oxygen	1.2 vol%;
Nitrogen	4.3 vol%;
Water	2.45 vol%;
Total sulphur	10 ppmv;
Hydrocarbons	3,120 ppmv; and
NOx	50 ppmv.

Supagas have installed the following equipment at the site to enable the carbon dioxide to be purified and liquefied.

Cold Water Scrubber. This dehumidifies the warm, moist carbon dioxide exiting the Shoalhaven Starches fermentation process and primarily removes water and alcohol from the feed stream. The scrubber waste stream is captured and reused by Shoalhaven Starches. The cold water scrubber is located on the Shoalhaven Starches site. The resulting carbon dioxide feed stream is piped (underground) to the Supagas plant. This pipe is approximately 690 m long and 200 mm nominal diameter.

Carbon Dioxide Compressor. The carbon dioxide compressor takes the carbon dioxide from the cold water scrubber and raises the pressure to approximately 1,950 kPag.

Sulphide Removal Unit. Carbon dioxide is fed into the beds that contain an active ingredient which removes any organic sulphides. This active ingredient is removed when spent and sent for disposal at an authorised facility.

CATOX System. The carbon dioxide is fed through a CATOX system (catalytic oxidation reactor) where the remaining hydrocarbons are oxidised into moisture and carbon dioxide. This system runs at approximately 330 degrees Celsius. The reaction process occurs with oxygen in a catalyst filled vessel.

Carbon Dioxide Driers. The carbon dioxide is further dried to a point where its moisture content is reduced to less than 20 parts per million. This occurs within one of two driers containing molecular sieves, i.e. one drier is on-line whilst the other drier is being regenerated.

Carbon Dioxide Liquefier. The dried, gaseous carbon dioxide at approximately 1,800 kPag is liquefied in a distillation column and condenser. An ammonia refrigeration system is used to condense the carbon dioxide (total ammonia capacity of approximately 700 kg).

Carbon Dioxide NOx Removal Vessel. Liquid carbon dioxide flows through a bed of molecular sieve. The molecular sieves adsorb any NOx. The molecular sieves are replaced as required and disposed of in accordance with statutory requirements.

Carbon Dioxide Tanks. The carbon dioxide is then stored in four tanks as follows:

- A 100 tonne tank. This tank is an insulated pressure vessel;
- A 200 tonne tank. This tank has a stainless steel inner tank and a low temperature carbon steel outer tank, i.e. if the inner tank fails then the carbon dioxide would be contained by the outer tank; and
- Two 150 tonne tanks. Each tank is 17.2 m high and 3.8 m diameter. These storage tanks are designed similarly to the existing 200 tonne tank, i.e. there is an inner and outer tank with the outer tank being designed to contain the carbon dioxide if the inner tank fails.

The carbon dioxide is transferred (as required) from the tanks into road tankers and then distributed to the market. There will be two types of road transport:

- A B-double capable of carrying a 30 tonne payload; and
- A single tanker that has a capacity of 20 tonnes.

Correspondingly, there is a maximum of two truck movements per day (delivering carbon dioxide to the market).

If the oxygen content in the carbon dioxide feed stream falls below 0.3 vol% then the CATOX system will not work effectively and the carbon dioxide purity will be off-specification.

Therefore, there is a backup oxygen supply from a 5.5 kL tank and also from high pressure cylinder packs on site (typically 6x G size cylinders).

Wastes from the plant includes:

- Waste water (blowdown) from the cooling tower is sent to the Shoalhaven Starches waste water treatment plant. This comes from the sump of the cooling tower and is undertaken to prevent total dissolved solids from building up that are naturally present in the water;
- The sulphide beds and NOx removal beds contain absorbents that when spent are sent as trade waste and replaced with new absorbent; and
- The cold water scrubber remove any residual alcohol and this is captured and reused by Shoalhaven Starches.

3.2 PROPOSED ALTERATIONS AND ADDITIONS

The proposed alterations and additions to the existing carbon dioxide plant involve similar plant and equipment. A process flow diagram is provided in Appendix A. A process description for the proposed plant is as follows.

1. ***Low Pressure Gas Supply***

Raw carbon dioxide gas is supplied at 0.1 barg and 30°C. It flows through a knock out drum (suction filter) to remove liquids and droplets before being compressed in the carbon dioxide booster.

The gas is then cooled in two heat exchangers (using cooling water and then ammonia) and further liquids are removed via another knock out drum.

2. ***Carbon Dioxide Compressor***

The carbon dioxide is then compressed to a pressure of up to 22 barg in a two-stage screw compressor.

The feed carbon dioxide stream is compressed up to 4.45 barg in the 1st stage. This compressed stream is combined with a gas balance line from the storage tanks / liquefaction area and a gas line from a carbon dioxide separator in order to recover boil-off gas.

At the outlet of 2nd stage, the carbon dioxide enters into carbon dioxide oil separator in which lubricating oil is separated by gravity and coalescing elements.

Lubricating oil is then cooled in the carbon dioxide / oil cooler heat exchanger (shell and tube) and then pumped by means of the carbon dioxide oil pump to the lubricating circuits of the screw compressor.

The high-pressure carbon dioxide exiting the carbon dioxide oil separator flows back to the cooling skid in which, after passing through the carbon dioxide oil coalescer, the residual content of oil in the carbon dioxide stream is reduced to a minimum.

3. CATOX

The hot compressed gas is processed in a guard beds to pre-remove the sulphur components and then in a CATOX unit to oxidize the hydrocarbons compounds, i.e. to form water and carbon dioxide.

The carbon dioxide gas must be preheated to activate the reaction (the temperature of the preheating depends on the type of the components inside the gas, usually the temperature is around 300/400°C).

The gas stream oxygen content is not enough to ensure the reaction so it is necessary introduce additional oxygen to guarantee the complete combustion of the hydrocarbons.

The carbon dioxide exiting the CATOX unit passes through an economiser (to save energy for CATOX pre-cooling), an aftercooler (using cooling water) and then a high pressure precooler (using ammonia). The temperature decreases from approximately 190°C to 10°C. There are moisture separators after the aftercooler and high pressure precooler.

4. Dryer

The drying system consists of two beds that ensure continuous operation, i.e. whilst the first bed is in operation, the other is in regeneration or in standby waiting for changeover.

Bed changeover takes place primarily based on time or mass (number of hours in service or the amount of carbon dioxide processed, i.e. whichever comes first causes a changeover to the fresh bed, while other bed starts it regeneration cycle.

Regeneration is achieved by the following sequence:

- Depressurisation of the regenerating vessel;
- Heating by means of an ambient air blower and heated up to approximately 200°C in the dryer regeneration heater;
- Cooling using storage tanks boil-off gases and non-condensables from liquefaction;
- Pressurisation of the regenerated vessel.

During the depressurisation and heating steps, the regenerating flow is vented to atmosphere while during the cooling step it is recovered to the inlet raw gas cooler line.

Downstream of the dryers a dust filter to avoid any particulate carryover to the liquefaction section.

There will be a dew point analyser installed at the outlet of the dryers. This instrument ensures the correct changeover between the two dryer vessels and also provide an important alarm in case of water breakthrough that can cause blockages in the downstream equipment.

5. Liquefaction

The dried carbon dioxide vapour stream passes through the tube side of the stripper column reboiler, i.e. to provide heat for the distillation process within the stripper.

After passing through the reboiler, the carbon dioxide stream flows to the carbon dioxide condenser where it is liquefied (approximately -28°C) by means of low pressure ammonia. The ammonia vaporises (operating pressure around 0.2 barg) and flows back to the suction of the ammonia compressor.

The liquid carbon dioxide stream from the carbon dioxide condenser flows by gravity down the stripper. Due to vapour rising from the reboiler, the non-condensable impurities are reduced to meet the required carbon dioxide specification for storage.

There will be a vent condenser that uses liquid carbon dioxide at low pressure to cool and condense the gas carbon dioxide recovered from carbon dioxide condenser. This condensed liquid is returned to the stripper.

Product liquid from the bottom of the stripper flows via a subcooler (in which the liquid carbon dioxide is cooled to approximately -27°C) to the NOx cold trap.

6. NOx Cold Trap

Liquid carbon dioxide exiting the liquefaction section passes through a lead-lag configuration of two vessels filled with molecular sieves before being sent to the pump skid. These vessels are the NOx cold trap where NOx (in particular, NO_2) is removed so that the final product specifications can be achieved.

The lead-lag configuration allows continuous operation. When one vessel (the first in contact with liquid carbon dioxide) is exhausted then bed regeneration (heating and cooling) can be performed. The status of each vessel can be checked by manually sampling the gas from the sampling valves after each vessel.

7. Liquid Carbon Dioxide Pumps

Liquid carbon dioxide from the NOx cold trap section is sent to the carbon dioxide pump buffer vessel. There are two liquid carbon dioxide pumps (duty / standby) that transfer the liquid carbon dioxide to the required storage tank.

The carbon dioxide pumps have minimum flow recirculation lines to keep the pumps cool and provide deadhead protection.

All liquid carbon dioxide lines will be fitted with thermal relief valves in case the liquid is isolated and heated (and hence creating thermal overpressure).

8. Ammonia Refrigeration

Gaseous ammonia from the liquefaction skid enters the ammonia compression package consisting of a single stage screw compressor.

The ammonia vapour stream is compressed to approximately 15 barg and enters an ammonia / oil separator in which lubricating oil is separated by gravity and coalescing elements.

The lubricating oil is then cooled in the ammonia / oil cooler and then pumped to the lubricating circuits of the screw compressor.

Compressed ammonia exiting the compressor is condensed in the ammonia condenser and then the liquid ammonia flows into the ammonia receiver. The ammonia then flows to various heat exchangers, e.g. the carbon dioxide condenser, for cooling and/or condensing purposes. The gaseous ammonia from these heat exchangers then return to the ammonia compressor.

9. Storage Tanks

It is proposed to install two additional vertical storage tanks as part of the project. These tanks will be 200 tonne capacity. Each tank will be 23 m high and 4.33 m diameter. These storage tanks are to be designed similarly to the existing 150 tonne tanks, i.e. there is an inner and outer tank with the outer tank being designed to contain the carbon dioxide if the inner tank fails.

There are two main vents for the proposed second carbon dioxide plant, i.e. an ammonia vent (e.g. for pressure safety valves) and a carbon dioxide vent. These are to be vented at a safe height to allow dispersion of the gases prior to potentially impacting people.

Given the extra capacity from the proposed second carbon dioxide plant then there will be approximately five truck movements per day delivering carbon dioxide to the market.

4 HAZARD IDENTIFICATION

4.1 HAZARDOUS MATERIALS

The main hazardous materials involved with the existing and proposed second carbon dioxide plants are:

- Carbon dioxide;
- Oxygen; and
- Ammonia.

There are low concentrations of hydrocarbons in the feed gas (insufficient to make the feed gas flammable though).

4.1.1 Carbon Dioxide

Carbon dioxide is a colourless gas with a slightly noticeable odour. It is not flammable or acutely toxic. At high concentrations, it can displace air and is therefore an asphyxiant.

It has a sublimation point of -78^{o}C. In either a liquid or solid form, it has the potential for cold burns.

Carbon dioxide is slightly soluble in water and results in an acidic solution of approximate pH of 4. At elevated temperatures, this solution is corrosive towards some steels, e.g. carbon steel.

Carbon dioxide is a greenhouse gas. It is used in the food industry, e.g. bubbles in soft drinks and beer. The gas is heavier than air and hence may accumulate in confined spaces and pose asphyxiation risks.

The following information on the health impacts from carbon dioxide is from AS2885 (the Australian Standard for Pipelines—Gas and Liquid Petroleum).

Table 2 – Carbon Dioxide Health Impacts

CO_2 Concentration	Health Impacts
0.5%	Long-term exposure limit in major jurisdictions
1%	Slightly increased breathing rate
2%	Doubled breathing rate, headache, tiredness
5%	Very rapid breathing, confusion, vision impairment
8 – 10%	Loss of consciousness after 5 to 10 minutes
>10%	More rapid loss of consciousness, death if not promptly rescued

4.1.2 Oxygen

Oxygen is not flammable but it strongly supports combustion (i.e. when concentrations are greater than 25%). This includes the combustion of steels as well as soft goods such as some plastics and rubbers.

In summary, oxygen promoted fires can occur due to the following main circumstances:

- The presence of hydrocarbons within oxygen systems;
- Adiabatic heat of compression; and
- Velocity related ignitions such as particle impact generating local hot spots.

To minimise the risk of oxygen promoted fires, good design (e.g. choosing the correct materials of construction and restricting velocities through pipes) and good maintenance practices (e.g. dedicated clean rooms for valve and equipment maintenance) are necessary.

Another risk of oxygen involves workers who are exposed to large quantities of the gas. It is possible that clothing can become saturated with oxygen. On ignition, the clothing can spontaneously burn.

Oxygen poses on-site hazards only.

4.1.3 Ammonia

Anhydrous ammonia is toxic and flammable (Dangerous Good (DG) Class 2.3 gas). It is a gas at normal temperature and pressure but may be liquefied under moderate pressure (630 kPag at 15^{o}C) or at temperatures below -33^{o}C at atmospheric pressure.

At low concentrations in air, ammonia vapour irritates the eyes, nose and throat. Ammonia is very soluble in water, therefore as it enters the body, it is readily absorbed. Irritation is immediate and local to the point of entry. Inhalation of high concentrations produces a sensation of suffocation and quickly causes burning of the respiratory tract and may result in death.

Anhydrous liquid ammonia causes severe burns on contact with the skin and if swallowed, it will cause very severe corrosive in the mouth, throat and stomach. Severe eye damage may result from direct contact with the liquid or exposure to high gas concentrations. Long term disability is mainly due to corneal and respiratory injuries.

The exposure limits for ammonia are summarised in the following table.

Table 3 – Ammonia Exposure Limits

Material	Odour Threshold	Exposure Limit (ppm)		IDLH (ppm)	Injury mechanism
		TWA	STEL		
Ammonia	5 to 53 ppm	25	35	300	Irritant

Ammonia is flammable in air in a concentration range of 16 - 25% by volume but it does not readily ignite (the minimum ignition energy is 100 mJ, compared with 0.29 mJ for methane). Ignition is therefore difficult and the probability of an explosion in the open air is low. The auto-ignition temperature of ammonia is 651^{o}C (relatively high compared to hydrocarbon materials).

Ammonia decomposes into flammable hydrogen gas at approximately 450^{o}C.

Given the difficulty of ignition, the relatively high flammability range and typical operating conditions, ammonia storage and handling installations are not generally regarded as significant fire or unconfined explosion hazards.

Water spray can be used to absorb vapour releases but should not be sprayed on pools of liquid ammonia as this will cause the liquid to rapidly vaporise (ammonia dissolves exothermically in water). If water is used for vapour absorption, a minimum of 100 volumes of water must be available for each volume of ammonia.

The transport of liquefied ammonia in a tank or bulk container made of quenched and tempered steel is prohibited unless the liquefied ammonia contains not less than 0.2wt% water. Stress corrosion cracking can occur, e.g. due to the presence of oxygen in ppm, if water is not present for these materials of construction.

4.2 Potential Hazardous Incidents Review

In accordance with the requirements of *Guidelines for Hazard Analysis*, (Ref 3), it is necessary to identify hazardous events associated with the facility's operations. As recommended in HIPAP 6, the PHA focuses on "atypical and abnormal events and conditions. It is not intended to apply to continuous or normal operating emissions to air or water".

In keeping with the principles of risk assessments, credible, hazardous events with ***the potential for off-site effects*** have been identified. That is, local events with limited impact or "slips, trips and falls" type events are not included nor are non-credible situations such as an aircraft crash occurring at the same time as an earthquake.

The identified credible, significant incidents with the potential for off-site impacts for the proposed facility are summarised in the Hazard Identification Word Diagram following (Table 4). This diagram presents the causes and consequences of the events, together with major preventative and protective features that are to be included as part of the design.

As the proposed alterations and additions to the existing carbon dioxide plant involve very similar plant and equipment then the potential hazardous events are the same.

Table 4 – Hazard Identification Word Diagram

Event Number	Hazardous Event	Causes	Consequences	Proposed Safeguards - Prevention Detection Mitigation
1	Loss of containment of carbon dioxide	Catastrophic pipe failures. Catastrophic equipment failures	A large release is required to adversely impact people given the data in Table 2. Smaller releases, when mixed with air in the turbulent jet, result in concentrations at the tip of the jet below 10% and hence unlikely to cause off-site impact or fatality	Piping and equipment to be constructed from Stainless Steel. Inspections and test plans for all major equipment items. Preventative maintenance of the piping and equipment items
2	Loss of containment of oxygen	Pipe or equipment failures, adiabatic heat of compression, incompatible materials used within the oxygen system	Potential for enhanced oxygen fires (local impact only). Cylinders (if used) may rocket	The oxygen system is to be designed and maintained to AS4041. All maintenance work on the oxygen system to be performed by oxygen trained personnel.
3	Loss of containment of ammonia	Piping or equipment failures, e.g. corrosion, impact, poor weld or fabrication fault. Procedural errors, e.g. valve left open	Release of gaseous and/or liquid ammonia. Ammonia, being a toxic gas, can affect people. Firewater used to absorb gaseous ammonia will form aqueous ammonia and hence there is a risk to the environment from the alkaline liquid	The ammonia refrigeration system is to be designed to AS1677. Equipment maintenance. Operating procedures for the refrigeration system. Firewater can be used, e.g. via the hydrants, to absorb ammonia gas. Ammonia vessels are to be only isolated for maintenance periods. The ammonia vessels are to be located in an area with low fire hazards

Given the types of hazardous materials with the potential for off-site impact, i.e. carbon dioxide and ammonia, the main risk is toxic exposure. This is assessed in the following section.

5 HAZARDOUS EVENTS ASSESSMENT

5.1 CARBON DIOXIDE RELEASES

The impact of concern from carbon dioxide exposure is health; it is not a flammable material. For the risk criteria in Table 1, health impacts of concern are irritation, injury and fatality.

Irritation and injury impacts in residential areas (the closest being 1.1 km away, i.e. Bomaderry) are usually estimated with the AEGL (acute exposure guideline levels) or ERPG (emergency response planning guidelines) values. However, AEGLs and ERPGs are not published for carbon dioxide. This is partly due to the relatively high concentrations required to cause impacts of these types (see Table 2) and hence the relatively short impact distances from a release to these levels. Therefore, irritation and injury impacts from carbon dioxide are not assessed in this PHA.

The important criterion from Table 1 is that the risk of fatality at 50×10^{-6} per year must remain on the site.

One level of fatal toxicity used by UK HSE (Health and Safety Executive) in relation to the provision of land use planning advice is termed the Specified Level of Toxicity (SLOT). The HSE has defined the SLOT as:

- Severe distress to almost everyone in the area;
- Substantial fraction of exposed population requiring medical attention;
- Some people seriously injured, requiring prolonged treatment; and
- Highly susceptible people possibly being killed.

The SLOT value for carbon dioxide is 1.5×10^{40} ppm^{8}.min (provisional value). Hence, for a 1 minute exposure, the required average concentration is 105,200 ppm (or 10.5 vol%), or for a 15 minute exposure, the required average concentration is 75,000 ppm (or 7.5 vol%). The SLOT values are used to determine if fatality at the nearest place of residence and site boundary from a release is possible.

The above SLOT values are consistent with the data in Table 2, i.e. a high carbon dioxide concentration is required to cause fatality.

A 15 minute release duration is taken in this PHA to allow for manual shutdown if a large release occurs. This can involve the Manildra operators who are on-site 24/7, i.e. they can stop the carbon dioxide supply at the fermenters if there is a problem with the carbon dioxide plant.

Scenarios that can cause high carbon dioxide concentrations downwind are:

1. Releases from the 690 m supply pipe to the plant;
2. Releases from the process piping and equipment downstream of the compressors;
3. Catastrophic failure of the storage vessels; and
4. Releases during road tanker transfers.

5.1.1 Low Pressure Pipe Carbon Dioxide Releases

Data for long pipeline failures is available from a number of sources but one of the most recent, comparable data set for long underground pipelines is from the UK's Health and Safety Executive (HSE) (Ref 6).

The HSE have researched pipeline releases in the UK over a 45 year period and determined a current failure rate of approximately $2.8x10^{-5}$/yr.km. This is for small, medium and large releases. Note that it is assumed in the HSE data that the pipelines are in use 100% of the time.

Hence, for a 0.69 km pipeline, the failure rate is approximately $1.9x10^{-5}$/yr. As 20 to 60% of pipeline failures are due to third party activities (Ref 7), e.g. construction or farm workers using excavators, and the pipe is to remain on Manildra property then the likelihood of failure is expected to be lower, i.e. in the order of $1x10^{-5}$/yr (or lower).

When the pipe is aboveground at the plant and fed to the compressors, failures can also occur here.

The existing carbon dioxide plant has a capacity of 90 TPD (at 91.7 vol% carbon dioxide) or 1 kg/s. The proposed second carbon dioxide plant will have a capacity of 75 TPD or 0.9 kg/s.

The existing carbon dioxide plant has two feed gas compressors, i.e.:

- Siad Carbon Dioxide Compressor=65 TPD; and
- Mehrer Carbon Dioxide Compressor= 25TPD

The proposed 75 TPD plant will have an additional compressor (Mayekawa) with a capacity of 75 TPD (or 0.9 kg/s). The total raw gas capacity is then 165 TPD or 1.9 kg/s, i.e. for the common feed gas pipe before it splits to the three compressors.

This release rate was modelled in TNO's EFFECTS program using the meteorological data shown in Appendix B and a ground terrain of regular large obstacles.

Based on the results in the previous revisions of this PHA, the point of maximum risk is at the western boundary opposite the 200 te carbon dioxide storage tank, i.e. this point includes the existing risk contributors such as the plant (carbon dioxide and ammonia) and the adjacent carbon dioxide storage tanks and road tanker loading. This revised PHA assesses the new levels of risk at this point for boundary fatality risk. Irritation and injury risk (for ammonia) is discussed in the ammonia analysis sections below.

A summary of all carbon dioxide release modelling for the existing plant is shown in Table 5. The “Low Pressure Pipe Catastrophic Failures” results apply to the common site feed gas pipe from Shoalhaven Starches, i.e. 1.9 kg/s total flow.

As can be seen from the results in Table 5, only the F1.5 condition results in the potential for off-site fatality for the site feed pipe.

The risk associated with these scenarios are included in Section 6.

Given the low potential impact from catastrophic low pressure pipe failures at full plant rates then modelling of smaller release sizes is not warranted.

5.1.2 Plant (High Pressure) Carbon Dioxide Releases

There are various scenarios for high pressure carbon dioxide releases, i.e.:

- Hole in a vessel or pipe with the pressure remaining high; and
- Catastrophic vessel failure, i.e. an instantaneous release.

If the plant continues to run after a catastrophic failure then the release will essentially be the compressor rate, e.g. approximately 90 TPD maximum for the existing plant or 1 kg/s carbon dioxide, with a low pressure driving force, i.e. the results in Section 5.1.1 will apply. The risk associated with these scenarios are included in Section 6.

High Pressure Carbon Dioxide Release through a Hole:

When gases or vapours are released at high pressure, a turbulent jet is formed. This jet draws in a significant quantity of air and hence the concentration within the jet decreases. A good rule-of-thumb is that a turbulent jet draws in at least 10 volumes of air.

This scenario was modelled in EFFECTS using the Turbulent Free Jet model. The distance to 7.5% carbon dioxide is approximately 9 m from the point of the release (along the axis). This is for a 50 mm hole at 22 barg (20 C). The release rate is estimated to be approximately 7.9 kg/s, i.e. higher than the compressor capacity, and hence the plant will depressurise.

Therefore, fatality risk at the site’s boundary is not predicted as the potential high pressure carbon dioxide release points are greater than 9 m from the boundary for the existing and proposed plants.

Instantaneous Release from a Pressure Vessel Catastrophic Failure:

To potentially cause fatality off-site, the amount of carbon dioxide vapour released instantaneously will need to be approximately 400 kg or larger, i.e. the vessel volume would need to be 8 m^3 or larger. Other than the storage tanks (assessed separately below), there are no other process vessels in the existing or proposed plants that are this large. Therefore, these pressure vessel carbon dioxide releases do not need to be included in the risk analysis.

5.1.3 Carbon Dioxide Storage Tank Failures

The existing plant stores liquid carbon dioxide within four tanks (1x 100, 1x 200 and 2x 150 te capacities). The pressure is approximately 18 barg (saturation temperature of approximately -22 C). The corresponding tanks' volumes are approximately 91, 182 and 2x 150 m^3.

When liquid carbon dioxide at saturated conditions is depressurised to ambient pressure, it forms solid carbon dioxide (dry ice) and vapour. The solid carbon dioxide will sublime, over time, with heat ingress.

Given the storage conditions, the percentage of vapour formation when the liquid carbon dioxide is flashed to ambient pressure is approximately 56 wt% (carbon dioxide Mollier Diagram, Planck and Kuprianoff). This flash vapour will combine with the vapour within the tank's ullage to then disperse downwind as a heavy gas.

If average tank level conditions are initially taken for the 100 te tank, i.e. 50% full, then the tank ullage vapour is approximately 0.5 x 91 m^3 x 50 kg/m^3 = 2,275 kg. When this is combined with the flash vapour, i.e. 50 te x 0.56 = 28 te, then the total cold carbon dioxide vapour instantaneously released is approximately 31 te.

The modelling results of instantaneously releasing 31 te of cold carbon dioxide vapour are shown in Table 5.

Based on the modelling results then off-site fatality risk is possible for all weather / wind conditions at the point of maximum risk at the boundary. This conclusion is also true for releases from the larger tanks, i.e. the existing 200 te and 2x 150 te tanks and the proposed 2x 200 te tanks.

The risks associated with these scenarios are included in Section 6.

Releases from potential holes in the tanks will form turbulent jets with the same conclusions made in Section 5.1.2, i.e. rapid dilution within the jet and no expected off-site fatality risk.

5.1.4 Road Tanker Transfer Releases

There are two main sources of releases during road tanker transfers:

1. Releases from the liquid transfer system; and

2. Vapour releases from the vapour recovery system.

The main causes for these potential releases are failures of the transfer hoses and connections.

A typical transfer rate of 1,500 LPM (approximately 26 kg/s) is used for these calculations. As the transfers are supervised by the drivers, emergency response to isolate the leak is expected to be immediate. However, a 10 minute response time is used. This allows for remote as well as local isolation.

Liquid Releases:

As discussed in Section 5.1.3, liquid carbon dioxide will flash to dry ice and vapour when released to ambient pressure. The flash vapour is approximately 56 wt%. This equates to 26 kg/s x 0.56 = 15 kg/s vapour for 10 minutes. This is modelled as a dense gas within EFFECTS and the results are shown in Table 5.

The carbon dioxide concentration of 7.5% remains close to the point of release for all weather / wind conditions. Therefore, off-site fatality is not expected.

Vapour Releases:

Releases from potential vapour transfer system failures for road tanker loading will form turbulent jets with the same conclusions made in Section 5.1.2, i.e. rapid dilution within the jet and no expected off-site fatality risk.

Table 5 – Carbon Dioxide Release Modelling Results – Existing Plant

	Fatality Risk Off-Site (Y/N) (Distance to 7.5%)		
Stability Class:	**Low Pressure Pipe Catastrophic Failures**	**Tank Catastrophic Failures**	**Liquid Release during Road Tanker Transfers**
A2	N	Y (70 m)	N
B3	N	Y (79 m)	N
C5	N	Y (104 m)	N
D5	N	Y (113 m)	N
E3	N	Y (109 m)	N
F1.5	Y (40 m)	Y (101 m)	N

Notes for Table 5:

1. The minimum distance from the plant to the nearest property boundary is 12 m.
2. The existing plant low pressure pipe is approximately 20 m from the maximum risk point of interest at the eastern boundary.

Table 6 – Carbon Dioxide Release Modelling Results – Proposed Plant

	Fatality Risk Off-Site (Y/N) (Distance to 7.5%)	
Stability Class:	**Tank Catastrophic Failures**	**Liquid Release during Road Tanker Transfers**
A2	Y (96 m)	N
B3	Y (108 m)	N
C5	Y (142 m)	N
D5	Y (156 m)	N
E3	Y (154 m)	N
F1.5	Y (147 m)	N

Notes for Table 6:

1. The catastrophic tank failures are for the proposed two 200 kL tanks.

5.2 AMMONIA RELEASES

The impact of concern from ammonia exposure is health. Whilst it is also flammable, it is difficult to ignite in the open. For the risk criteria in Table 1, health impacts of concern are irritation, injury and fatality.

The existing ammonia refrigeration system at the site holds approximately 700 kg (typically, large industrial refrigeration systems hold an order of magnitude or more ammonia). The proposed second carbon dioxide plant will also have an ammonia refrigeration system of approximate capacity 1,670 kg.

For the existing plant during normal operation, the majority of the ammonia is in liquid form and held within the ammonia receiver (approximately 14.5 barg), the non-condensable stripper column condenser and the supply surge drum (approximately ambient pressure, i.e. -33 degrees Celsius). For modelling purposes, it is assumed that approximately 300 kg of liquid ammonia is within each system.

For the proposed second carbon dioxide plant, there will be the following equipment items that contain ammonia:

- The ammonia / oil separator (ammonia vapour only);
- The ammonia condenser and receiver;
- The open flash separator; and
- The auxiliary boiler, subcooler and carbon dioxide condenser.

For modelling purposes, it is assumed that approximately 400 kg of liquid ammonia is within each system for the proposed plant.

The major potential losses of containment of ammonia can be from:

- Vessel failures; and
- Piping failures.

Smaller releases can also occur from seal or gasket failures and losses of containment when topping up the ammonia charge. The relatively small release diameters for these releases do not pose significant off-site risks.

The original modelling was performed using TNO's EFFECTS program. The catastrophic vessel failures modelling are now performed in ALOHA as there were some inconsistent results with EFFECTS. The ALOHA results are typically more conservative than EFFECTS.

Toxic Impact of Ammonia

The toxicity effects of ammonia are summarised in Table 7

Table 7 - Effects of Ammonia

Exposure Level (ppm)	Duration (mins)	Effects
25	60	ERPG 1
150		ERPG 2
1,500		ERPG 3

The three ERPG (emergency response planning guidelines) tiers are defined as follows:

ERPG-3 is the maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects.

ERPG-2 is the maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action.

ERPG-1 is the maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing more than mild, transient adverse health effects or without perceiving a clearly defined objectionable odour.

ERPG 1 (25 ppm) and 2 (150 ppm) are taken as the limits for irritation and injury, respectively.

The above exposure limits are quite conservative given the following information from the Australian Standard (AS2022) for ammonia (Ref 8):

Up to 100 ppm – no adverse effect for the average worker with no deliberate exposure for long periods permitted

400 ppm – immediate nose and throat irritation with no serious effect after 30 minutes to one hour

700 ppm – immediate eye irritation with no serious effect after 30 minutes to one hour

1,700 ppm – convulsive coughing, severe eye, nose, and throat irritation; could be fatal after 30 minutes

2,000-5,000 ppm – convulsive coughing, severe eye, nose, and throat irritation; could be fatal after 15 minutes

Over 5,000 ppm – respiratory spasm, rapid asphyxia and fatal within minutes

The SLOT value for ammonia is 3.78×10^8 $ppm^2.min$. Hence, for a 1 minute exposure, the required average concentration is 19,440 ppm, or for a 15 minute exposure, the required average concentration is 5,020 ppm. The SLOT values are used to determine if fatality at the nearest site boundary from a release is possible.

Ammonia Release Cases Modelled

The following scenarios involving ammonia releases were modelled for the six dominant stability classes and wind speeds in Appendix B. Concentrations at the nearest residential area and the site boundary are calculated.

1. Catastrophic vessel failures. The release quantity is taken as 300 kg of liquid ammonia (instantaneous release, i.e. exposure time up to 1 minute) for the existing plant and 400 kg of ammonia for the proposed plant.

2. Liquid releases from piping and vessel failures corresponding to the various hole sizes (15 minutes duration).

3. Vapour releases from piping and vessel failures corresponding to the various hole sizes (15 minutes duration).

Scenario 1 – Catastrophic Vessel Failures:

The results for Scenario 1 above (***existing plant***) are shown in Table 8. The modelling is performed based on low obstacles as the ammonia plume will largely travel through open country.

The suburb of Terara (situated approximately 1.3 km to the south of the site across the Shoalhaven River) is the closest residential area of interest. Therefore, the probabilities of the weather / wind conditions are from the north.

Table 8 – Ammonia Release Modelling – Catastrophic Failures – Existing Plant

Stability Class / Wind Speed	Concentration (ppm) at Residential Area (1.3 km)	Concentration (ppm) at the Boundary (12 m)
A2	3	147,000
B3	4	135,000
C5	10	142,000
D5	21	279,000
E3	63	> 500,000
F1.5	101	> 500,000

Given the results in Table 8 then irritation but not injury is possible at residential areas (E3 and F1.5 conditions).

For a 1 minute exposure, the required average concentration (SLOT) is 19,440 ppm. This value is exceeded for all the weather / wind conditions and hence off-site fatality is possible.

The results for Scenario 1 above (***proposed plant***) are shown in Table 9.

Table 9 – Ammonia Release Modelling – Catastrophic Failures – Proposed Plant

Stability Class / Wind Speed	Concentration (ppm) at Residential Area (1.3 km)	Concentration (ppm) at the Boundary (31 m)
A2	4	29,100
B3	6	26,700
C5	13	28,400
D5	28	56,000
E3	84	222,000
F1.5	134	666,000

Given the results in Table 9 then irritation but not injury is possible at residential areas (D5, E3 and F1.5 conditions).

For a 1 minute exposure, the required average concentration (SLOT) is 19,440 ppm. This value is exceeded for all the weather / wind conditions and hence off-site fatality is possible.

The corresponding risks are analysed in Section 6 of this PHA.

Scenario 2 – Liquid Releases:

Liquid ammonia releases can occur from the following equipment items in the existing carbon dioxide plant:

- The ammonia condenser / receiver;
- The intercooler drum; and
- The ammonia low stage surge drum.

Liquid ammonia releases can occur from the following in the proposed carbon dioxide plant:

- The ammonia condenser / receiver;
- The open flash separator; and
- The auxiliary boiler, subcooler and carbon dioxide condenser.

For the existing plant, the liquid ammonia flowrate to the CO_2 condenser is approximately 1,226 kg/hr (0.34 kg/s). The liquid ammonia flowrate for the proposed plant is 905 kg/hr (0.25 kg/s). These liquid flowrates are limited by a relatively small pipe size, e.g. 25 mm to the proposed second carbon dioxide plant subcooler. It is initially assumed that a leak is restricted by the flowrates. The modelling results for the highest ammonia flowrate (i.e. the existing plant) are shown in Table 10. These results will be conservative for the proposed plant but indicative.

Table 10 – Ammonia Liquid Release Modelling

Stability Class / Wind Speed	Concentration (ppm) at Residential Area (1.3 km)	Concentration (ppm) at the Boundary
A2	1.5	260
B3	2	260
C5	3	260
D5	5	260
E3	8	260
F1.5	8	255

From the results shown in Table 10, off-site irritation and injury are not expected at residential areas and also there is no off-site fatality risk.

However, large hole diameter liquid releases could (for a short time) exceed the design flowrate through the ammonia refrigeration system. These releases could rapidly drain the liquid ammonia from the system.

The estimated leak rates (using EFFECTS) are shown in Table 11. The vessels in both the existing and proposed plants will operate at similar ammonia pressures and temperatures.

Table 11 – Ammonia Liquid Release Rates

	Liquid Ammonia Flowrate, kg/s	
	50 mm Hole	25 mm Hole
Ammonia Receivers (14.6 barg)	50	12
Intercooler Drum / Open Flash Separator (3.5 barg)	25	6.4
Ammonia Low Stage Surge Drum / CO2 Condensers (approximately 0 barg)	4	1

As the inventory of the main vessels containing liquid ammonia is approximately 300 kg in the existing plant and 400 kg in the proposed plant, the 50 mm and 25 mm hole diameter scenarios for the ammonia receivers and intercooler drum / open flash separator are essentially instantaneous failures (normally taken to be a release of 1 minute or less). The results from Table 8 and Table 9 can be used for these scenarios.

As the liquid piping is expected to be relatively small diameter, e.g. 25 mm, then catastrophic pipe failures will yield the same results as a 25 mm hole in a vessel.

The corresponding risks are analysed in Section 6 of this PHA.

Modelling of a 1 kg/s ammonia release (Table 12) shows that off-site impact, i.e. irritation and injury at residential areas and fatality beyond the boundary, are not expected. The results in Table 14 are indicative for a larger 3.1 kg/s release rate with the same conclusion, i.e. no significant off-site impacts.

Table 12 – Ammonia Liquid (1 kg/s) Release Modelling

Stability Class / Wind Speed	Concentration (ppm) at Residential Area (1.3 km)	Concentration (ppm) at the Boundary
A2	4	260
B3	4	260
C5	5	260
D5	6	260
E3	7	260
F1.5	7	258

Scenario 3 – Vapour Releases:

Ammonia vapour releases can occur from any of the piping or equipment at the three pressure levels within the refrigeration systems for both the existing and proposed plants, i.e. the ammonia receivers, the intercooler drum / open flash separator and the ammonia low stage surge drum / carbon dioxide condensers.

The estimated vapour leak rates (using EFFECTS) are shown in Table 13.

Table 13 – Ammonia Vapour Release Rates

	Ammonia Vapour Flowrate, kg/s	
	50 mm Hole	25 mm Hole
Ammonia Receivers (14.6 barg)	3.1	0.8
Intercooler Drum / Open Flash Separator (3.5 barg)	1	0.2
Ammonia Low Stage Surge Drum / CO_2 Condensers (approximately 0 barg)	Note 1	Note 1

Note 1: Flowrate is less than 1 kg/s which has been shown to not cause off-site irritation, injury or fatality risk.

From the modelling in Table 12 for a 1 kg/s ammonia release, off-site impacts, i.e. irritation and injury at residential areas and fatality beyond the boundary, are not expected. Therefore, the corresponding vapour releases can be ignored in the analysis.

Modelling of a 3.1 kg/s ammonia release (Table 14) shows that off-site impact, i.e. irritation and injury at residential areas and fatality beyond the boundary, are not expected.

Table 14 – Ammonia Vapour (3.1 kg/s) Release Modelling

Stability Class / Wind Speed	Concentration (ppm) at Residential Area (1.3 km)	Concentration (ppm) at the Boundary
A2	5	260
B3	5	260
C5	6	260
D5	6	260
E3	6	260
F1.5	7	255

5.3 ROAD TRANSPORT INCIDENTS

Chemicals transported by road will, where relevant, be transported in accordance with the Australian Code for the Transport of Dangerous Goods by Road and Rail.

The expected frequency and quantity of deliveries of the bulk Dangerous Goods to the site is given in Table 15.

Table 15 – Bulk Chemicals Road Transport Frequencies

Material Transported	Approximate Number of Transport Movements
Carbon Dioxide (DG 2.2)	5 per day
Ammonia (DG 2.3, 8)	Note 1
Oxygen (DG 2.2, 5.1)	Note 2

Notes:

1. Ammonia deliveries will be infrequent as once the refrigeration is filled, only occasional charging will be required, i.e. to make up for losses.

2. Approximately one road tanker transfer per month and two oxygen packs per year.

If a road tanker carrying carbon dioxide is involved in an accident and the vessel integrity is lost then there is the potential for serious injury and fatality for people involved in the accident or those nearby due to asphyxiation.

Causes for road tanker accidents are summarised in Table 16 (Ref 9).

The CCPS guidelines (Ref 9) quote a figure of approximately 2 accidents/year (for all causes) per 10^6 miles, i.e. $1.2x10^{-6}$ accidents per kilometre per year.

Transport studies for NSW roads, e.g. Ref 10, has found the following typical heavy vehicle accident rates for similar road routes:

> 0.016 - 2.96 Heavy Vehicle Accidents/Annual Million km of Heavy Vehicle Travel

In the event of an accident involving a heavy vehicle, the carried goods may or may not be released. The probability of release is dependent on factors such as speed, shipping conditions (i.e. pressurised versus non-pressurised), inadequate load securing, and strength and integrity of the container.

Table 16 – Causes for Road Tanker Accidents

Human Error	Equipment Failures	System or Procedural Failures	External Events
• driver impairment, e.g. alcohol or drugs • speeding • driver overtired • driver exceeding safe working hours • enroute inspection • contamination • overfilling • other vehicle's driver • taking tight turns/ramps too quickly (overturns) • unsecured loads	• non-dedicated trailer • rail road crossing guard failure • leaking valve • leaking fitting • brake failure • relief device failure • tyre failure • soft shoulder • overpressure • material defect • steering failure • sloshing • high centre of gravity • corrosion • bad weld • excessive grade • poor intersection design • road chamber/width • suspension system • tyre fire caused by friction, brakes overheating or exploding tyres give sparks due to metal in the rubber) • fuel tank fire (diesel)	• driver incentives to work longer hours • driver training • carrier selection • container specification • route selection • emergency response training • speed enforcement • driver rest periods • maintenance • inspection • time of the day restrictions	• vandalism/sabotage • rain • fog/visibility • wind • flood/washout • fire at rest area/parking areas • earthquake • existing accident • animals on road

Various studies of release probabilities from heavy vehicles involved in an accident have been undertaken. The *Guidelines for Chemical Transportation Risk Analysis* (Ref 9) indicates that the release probability for various road types is between 5 and 10% (i.e. approximately one heavy vehicle accident in every 10 to 20 will result in a release of the material). The probability of fatality then has to be taken into account but this will depend on factors such as the leak size.

Given the history of road tanker transport in NSW, compliance with the Australian Dangerous Goods Code (an indicator of achieving SFARP (so far as reasonably practicable)) and the above representative data then the risk of an accident involving a vehicle transporting a hazardous material such as carbon dioxide resulting in a release of material is therefore relatively low.

5.4 NATURAL AND OTHER EXTERNAL HAZARDOUS EVENTS

The site has been assessed with regard to exposure to the following external hazards:

Subsidence	Landslide
Burst dam	Earthquake
Storm and high winds	Rising water courses
Flood	Storm water runoff
Lightning	Forest fire
Vermin/insect infestation	Security

Given the proposed location of the site, the significant hazard is flooding. The plant is to be built with to the relevant Australian Standards to mitigate the impact of flooding.

6 RISK ANALYSIS

6.1 HIPAP 4 RISK CRITERIA

As discussed in Section 5, the DoP risk criteria of importance for this site are:

- Irritation, injury and fatality risk at a place of residence; and
- Fatality risk to be contained within the boundary of an industrial site, i.e. no more than 50×10^{-6}/yr.

Given there are a minimal number of materials and events that can cause off-site impact, the analysis in this revised PHA was done by modelling the carbon dioxide and ammonia release cases for the six dominant stability class / wind directions to determine which events can contribute to off-site risk. The results are shown in Section 5.

These results are then analysed using event likelihoods (HSE UK 2012 data used, Ref 11) and the probability that the stability class / wind direction exists. The analysis is shown in Appendix C along with further explanation of the assumptions and data sources. The total estimated risks at the worst case residential area and the nearest site boundary are compared to the HIPAP 4 risk criteria (Ref 4) in Table 17.

The modelling results in this revision have been updated based on the proposed layout including the second carbon dioxide plant as well as up-to-date information on the existing installed equipment.

Table 17 – Comparison to HIPAP 4 Risk Criteria

Risk Type	HIPAP 4 Criteria	Estimated Risk or Likelihood	Comments
Irritation	50×10^{-6}/yr	4.8×10^{-6}/yr	Compliant
Injury	10×10^{-6}/yr	-	Compliant
Fatality	50×10^{-6}/yr	7.3×10^{-6}/yr	Compliant

6.2 CUMULATIVE AND PROPAGATION RISK

Given the rural location and the separation distances then it is reasonable to conclude that the modified plant does not make a significant contribution to the existing cumulative risk in the area. Compliance with the HIPAP 4 risk criteria (Table 17) is an indicator of a facility having limited cumulative risk impacts.

There is limited potential for on-site propagation events as the main hazardous events are releases of gas. As carbon dioxide is non-flammable (it is used to extinguish fires), releases will have limited impact (if any) on the adjacent equipment.

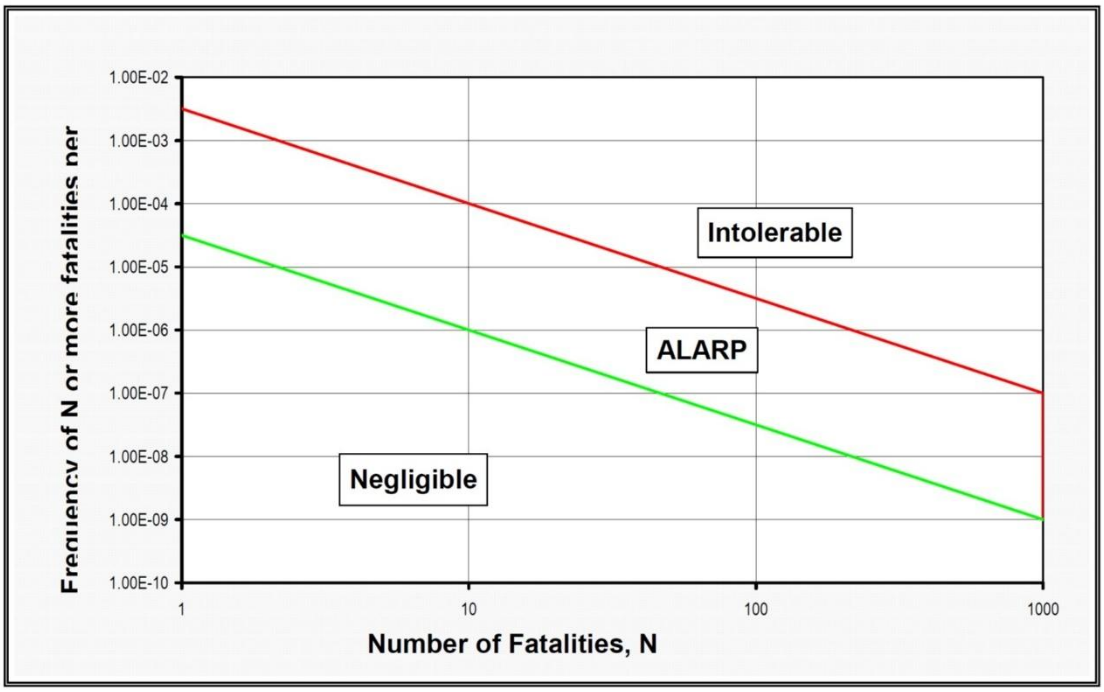
6.3 SOCIETAL RISK

Societal risk results are usually presented as F-N curves which show the frequency of events (F) resulting in N or more fatalities. To determine societal risk, it is necessary to quantify the population within each zone of risk surrounding a facility. By combining the results for different risk levels, a societal risk curve can be produced.

Societal risk is normally calculated where the 1 pmpy contour (or calculated risk level) approaches closely to residential areas or sensitive land uses or when events with very large consequence distances are being assessed. Hence, the potential exists for multiple fatalities as a result of a single accident.

The societal risk curve from HIPAP 4 (Ref 4) is shown below.

Figure 4 – Societal Risk Curve



From the analysis in Appendix C, the cumulative off-site individual fatality risk (using the UK HSE SLOT values which are equivalent to a low probability of fatality, e.g. 0.01) is approximately $7.3x10^{-6}$/yr. Given the rural location and the separation distances to major populations then societal risk is concluded to be acceptable.

6.4 RISK TO THE BIOPHYSICAL ENVIRONMENT

The main concern for risk to the biophysical environment is generally with effects on whole systems or populations. Whereas any adverse effect on the environment is obviously undesirable, to have an incident with such consequences requires exposure of a sensitive area to either large effect, short term releases or smaller effect, long term releases.

Given the limited number of events that can occur at this site with off-site impacts, the quantity and/or nature of the gases and their relatively low release likelihoods, the risk to biophysical environment is low. This has been shown by analysis in Section 6.1.

In summary, whilst off-site effects can be expected if a major release were to occur, there are no identified whole systems or populations which are at unacceptable levels of risk due to the potentially hazardous events reviewed in this PHA.

6.5 CONCLUSION AND RECOMMENDATIONS

The risks associated with the modified Supagas carbon dioxide plant at Bomaderry have been assessed and compared against the DoP risk criteria.

The results are as follows and show compliance with all risk criteria.

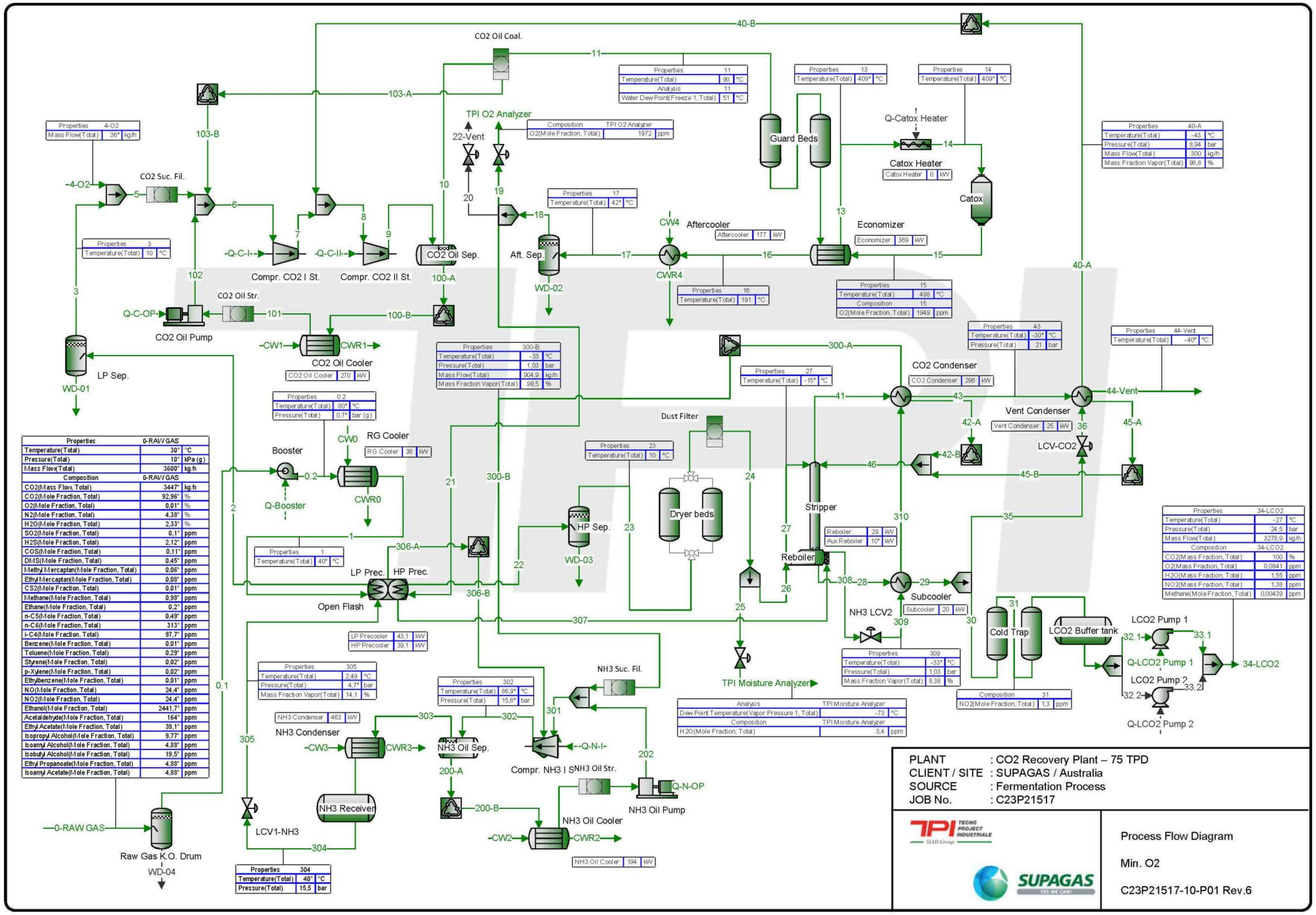
Description	Risk Criteria	Risk Acceptable?
Fatality risk to sensitive uses, including hospitals, schools, aged care	0.5×10^{-6} per year	Y
Fatality risk to residential and hotels	1×10^{-6} per year	Y
Fatality risk to commercial areas, including offices, retail centres, warehouses	5×10^{-6} per year	Y
Fatality risk to sporting complexes and active open spaces	10×10^{-6} per year	Y
Fatality risk to be contained within the boundary of an industrial site	50×10^{-6} per year	Y
Injury risk – incident heat flux radiation at residential areas should not exceed 4.7 kW/m^2 at frequencies of more than 50 chances in a million per year or incident explosion overpressure at residential areas should not exceed 7 kPa at frequencies of more than 50 chances in a million per year	50×10^{-6} per year	Y
Toxic exposure - Toxic concentrations in residential areas which would be seriously injurious to sensitive members of the community following a relatively short period of exposure	10×10^{-6} per year	Y
Toxic exposure - Toxic concentrations in residential areas which should cause irritation to eyes or throat, coughing or other acute physiological responses in sensitive members of the community	50×10^{-6} per year	Y
Propagation due to Fire and Explosion – exceed radiant heat levels of 23 kW/m^2 or explosion overpressures of 14 kPa in adjacent industrial facilities	50×10^{-6} per year	Y

Societal risk, area cumulative risk, propagation risk, transport risk and environmental risk are also concluded to be acceptable. The primary reasons for the low risk levels from the site are the separation distances between the hazards to the nearest place of residence and that high levels of carbon dioxide are required to cause fatality.

As the proposed alterations and additions to the existing carbon dioxide plant involve plant and equipment that are very similar in design to the existing plant and that the proposed modifications have already been reviewed using the HAZOP technique then there are no further recommendations made in this study.

7 APPENDIX A - PROCESS FLOW DIAGRAM

Appendix A – Process Flow Diagram



8 APPENDIX B - METEOROLOGICAL DATA

Appendix B - Meteorological Data

The following data is a summary of climate data obtained from the Bureau of Meteorology. The data summarises the local weather / wind conditions for various atmospheric stability classes and wind directions from 2010 to 2017.

	Stability Class / Wind Speed (m/s)						
Wind Direction	Percentages:						
	A2	**B3**	**C5**	**D5**	**E3**	**F1.5**	**Totals:**
N	1.5	2.2	1.4	3.9	0.5	5.8	15.4
NE	0.5	0.7	1.4	2.7	0.2	0.2	5.6
E	0.4	0.7	2.4	3.4	0.2	0.3	7.4
SE	0.3	0.6	1.6	3.6	0.2	0.5	6.8
S	0.2	0.6	2.4	10.8	0.5	0.8	15.4
SW	0.1	0.2	0.7	4.5	0.8	1.2	7.6
W	0.2	0.8	3.8	9.9	2.0	3.8	20.6
NW	0.6	2.0	3.9	9.3	2.3	2.9	21.1
Totals:	3.9	8.0	17.7	48.1	6.9	15.5	

9 APPENDIX C - RISK ANALYSIS

Appendix C - Risk Analysis

The risk analysis performed for this PHA is shown on the table below (pages A3.3 and A3.4)

The notes associated with the calculations and shown in the table are:

1. The pipe lengths are estimated using the site layout.

2. HSE UK data used for all likelihoods.

3. The number of pressure vessels includes the fixed bed vessels, heat exchangers and the columns.

4. The number of vessels holding up to 300 kg of liquid ammonia in the existing plant is assumed to be two, i.e. there is one ammonia receiver and one ammonia low stage surge drum. The number of vessels holding up to 400 kg of liquid ammonia in the proposed plant is assumed to be three, i.e. there is one ammonia receiver, one open flash separator and one condenser.

5. 50 mm and 25 mm holes can occur in the two main ammonia vessels in the existing plant and three main ammonia vessels in the proposed plant (see Point 4 above), i.e. that can result in exceeding the HIPAP 4 criteria.

6. The widths of the plumes were estimated in ALOHA. The probability that the wind is blowing towards the nearest residential area or site boundary is taken to be the plume angle divided by 45 degrees times the probability values for the wind blowing from the direction of interest. Outside of this arc, the plume is not expected to impact the point of interest.

7. Double-walled storage tank failure rate from HSE, Failure Rate and Event Data for use within Risk Assessments, 28/06/2012 (for failure of both the inner and outer tanks).

Risk Analysis:

Scenario	Stability Class Wind Speed	Pipe Length, m	Pipe Failure Likelihood, times/yr.m	Vessels Failure Likelihood, times/yr	Number of Vessels	Event Likelihood, times/yr	Probability of Wind Direction for Irritation and Injury	Probability of Wind Direction for Fatality	Contribution to the Following Risks:		
									Irritation	Injury	Fatality
Existing Plant:											
		Note 1:	Note 2:				Note 6:	Note 6:			
Carbon Dioxide - LP Pipe Failures	F1.5	30	2.00E-07			6.00E-06		0.001			6.00E-09
		Note 1:		Note 2:	Note 3:						
HP Release Through a Hole (with subsequent LP release)	F1.5	200	5.00E-07	4.00E-06	18	1.72E-04		0.001			1.72E-07
Carbon Dioxide 100 te Tank - Catastrophic Failure	A2			4.00E-06	1	4.00E-06		0.002			9.96E-09
	B3			4.00E-06	1	4.00E-06		0.004			1.74E-08
	C5			4.00E-06	1	4.00E-06		0.012			4.69E-08
	D5			4.00E-06	1	4.00E-06		0.009			3.63E-08
	E3			4.00E-06	1	4.00E-06		0.001			2.49E-09
	F1.5			4.00E-06	1	4.00E-06		0.001			2.40E-09
				Note 7							
Carbon Dioxide 200 and 2x150 te Tanks - Catastrophic Failures	A2			5.00E-08	3	1.50E-07		0.002			3.73E-10
	B3			5.00E-08	3	1.50E-07		0.004			6.53E-10
	C5			5.00E-08	3	1.50E-07		0.012			1.76E-09
	D5			5.00E-08	3	1.50E-07		0.009			1.36E-09
	E3			5.00E-08	3	1.50E-07		0.001			9.33E-11
	F1.5			5.00E-08	3	1.50E-07		0.001			9.00E-11
					Note 4						
Ammonia Vessels - Catastrophic Failures	A2			4.00E-06	2	8.00E-06		0.004			3.27E-08
	B3			4.00E-06	2	8.00E-06		0.004			3.48E-08
	C5			4.00E-06	2	8.00E-06		0.013			1.07E-07
	D5			4.00E-06	2	8.00E-06		0.017			1.33E-07
	E3			4.00E-06	2	8.00E-06	0.002	0.001	1.96E-08		7.82E-09
	F1.5			4.00E-06	2	8.00E-06	0.015	0.001	1.24E-07		6.40E-09
					Note 5:						
Ammonia (liquid) - 50 mm Holes	A2			5.00E-06	2	1.00E-05		0.004			4.09E-08
	B3			5.00E-06	2	1.00E-05		0.004			4.36E-08
	C5			5.00E-06	2	1.00E-05		0.013			1.33E-07
	D5			5.00E-06	2	1.00E-05		0.017			1.66E-07
	E3			5.00E-06	2	1.00E-05	0.002	0.001	2.44E-08		9.78E-09
	F1.5			5.00E-06	2	1.00E-05	0.015	0.001	1.55E-07		8.00E-09

Scenario	Stability Class Wind Speed	Pipe Length, m	Pipe Failure Likelihood, times/yr.m	Vessels Failure Likelihood, times/yr	Number of Vessels	Event Likelihood, times/yr	Probability of Wind Direction for Irritation and Injury	Probability of Wind Direction for Fatality	Contribution to the Following Risks:		
									Irritation	Injury	Fatality
					Note 5:						
Ammonia (liquid) - 25 mm Holes	A2			5.00E-06	2	1.00E-05		0.004			4.09E-08
	B3			5.00E-06	2	1.00E-05		0.004			4.36E-08
	C5			5.00E-06	2	1.00E-05		0.013			1.33E-07
	D5			5.00E-06	2	1.00E-05		0.017			1.66E-07
	E3			5.00E-06	2	1.00E-05	0.002	0.001	2.44E-08		9.78E-09
	F1.5			5.00E-06	2	1.00E-05	0.015	0.001	1.55E-07		8.00E-09
		Note 1:									
Ammonia (liquid) - 25 mm Pipe Failures	A2	50	1.00E-06			5.00E-05		0.004			2.04E-07
	B3	50	1.00E-06			5.00E-05		0.004			2.18E-07
	C5	50	1.00E-06			5.00E-05		0.013			6.67E-07
	D5	50	1.00E-06			5.00E-05		0.017			8.31E-07
	E3	50	1.00E-06			5.00E-05	0.002	0.001	1.22E-07		4.89E-08
	F1.5	50	1.00E-06			5.00E-05	0.015	0.001	7.73E-07		4.00E-08
Proposed Second Plant:											
		Note 1:	Note 2:	Note 2:	Note 3:		Note 6:	Note 6:			
HP Release Through a Hole (with subsequent LP release)	F1.5	200	5.00E-07	4.00E-06	21	1.84E-04		0.001			1.84E-07
				Note 7							
Carbon Dioxide 2x 200 te Tanks - Catastrophic Failures	A2			5.00E-08	2	1.00E-07		0.002			2.49E-10
	B3			5.00E-08	2	1.00E-07		0.004			4.36E-10
	C5			5.00E-08	2	1.00E-07		0.012			1.17E-09
	D5			5.00E-08	2	1.00E-07		0.009			9.07E-10
	E3			5.00E-08	2	1.00E-07		0.001			6.22E-11
	F1.5			5.00E-08	2	1.00E-07		0.001			6.00E-11
					Note 4						
Ammonia Vessels - Catastrophic Failures	A2			4.00E-06	3	1.20E-05		0.004			4.91E-08
	B3			4.00E-06	3	1.20E-05		0.004			5.23E-08
	C5			4.00E-06	3	1.20E-05		0.013			1.60E-07
	D5			4.00E-06	3	1.20E-05	0.019	0.017	2.29E-07		1.99E-07
	E3			4.00E-06	3	1.20E-05	0.002	0.001	2.93E-08		1.17E-08
	F1.5			4.00E-06	3	1.20E-05	0.015	0.001	1.86E-07		9.60E-09
					Note 5:						
Ammonia (liquid) - 50 mm Holes	A2			5.00E-06	3	1.50E-05		0.004			6.13E-08

Scenario	Stability Class Wind Speed	Pipe Length, m	Pipe Failure Likelihood, times/yr.m	Vessels Failure Likelihood, times/yr	Number of Vessels	Event Likelihood, times/yr	Probability of Wind Direction for Irritation and Injury	Probability of Wind Direction for Fatality	Contribution to the Following Risks:		
									Irritation	Injury	Fatality
	B3			5.00E-06	3	1.50E-05		0.004			6.53E-08
	C5			5.00E-06	3	1.50E-05		0.013			2.00E-07
	D5			5.00E-06	3	1.50E-05	0.019	0.017	2.86E-07		2.49E-07
	E3			5.00E-06	3	1.50E-05	0.002	0.001	3.67E-08		1.47E-08
	F1.5			5.00E-06	3	1.50E-05	0.015	0.001	2.32E-07		1.20E-08
					Note 5:						
Ammonia (liquid) - 25 mm Holes	A2			5.00E-06	3	1.50E-05		0.004			6.13E-08
	B3			5.00E-06	3	1.50E-05		0.004			6.53E-08
	C5			5.00E-06	3	1.50E-05		0.013			2.00E-07
	D5			5.00E-06	3	1.50E-05	0.019	0.017	2.86E-07		2.49E-07
	E3			5.00E-06	3	1.50E-05	0.002	0.001	3.67E-08		1.47E-08
	F1.5			5.00E-06	3	1.50E-05	0.015	0.001	2.32E-07		1.20E-08
		Note 1:									
Ammonia (liquid) - 25 mm Pipe Failures	A2	50	1.00E-06			5.00E-05		0.004			2.04E-07
	B3	50	1.00E-06			5.00E-05		0.004			2.18E-07
	C5	50	1.00E-06			5.00E-05		0.013			6.67E-07
	D5	50	1.00E-06			5.00E-05	0.019	0.017	9.53E-07		8.31E-07
	E3	50	1.00E-06			5.00E-05	0.002	0.001	1.22E-07		4.89E-08
	F1.5	50	1.00E-06			5.00E-05	0.015	0.001	7.73E-07		4.00E-08
									4.80E-06	0	7.31E-06

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