PRELIMINARY HAZARD ANALYSIS,
MODIFICATION TO APPROVED GAS FIRED
CO-GENERATION PLANT,
SHOALHAVEN STARCHES,
BOMADERRY, NSW
CONSENT NUMBER: MP 06_0228 MOD 23

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Preliminary Hazard Analysis, Shoalhaven Starches, Co-Generation Plant

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A	21/3/21	Draft for Comment	Shoalhaven Starches
B	28/8/21	Final Issue	Shoalhaven Starches
C	31/8/21	Tables 4 and 5 Updated	Shoalhaven Starches

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EXECUTIVE SUMMARY

The Shoalhaven Starches factory located on Bolong Road, Bomaderry, produces a range of products for the food, beverage, confectionary, paper and motor transport industries including starch, gluten, glucose and ethanol.

Shoalhaven Starches propose to construct a new gas-fired co-generation plant which will consist of two natural gas turbines that will generate an anticipated power output each of 30 MW, providing a total power to the site of 60 MW. The new gas fired co-generation plant will replace the approved gas fired and coal fired co-generators. In addition, Shoalhaven Starches also proposed to convert their existing coal fired boilers 2, 4, 5 and 6 to gas as well.

The waste heat from each of the gas turbine exhausts will be used to generate 11 barg steam in two 110 t/hr heat recovery steam boilers. The boilers will be co-fired with natural gas and will be able to operate at full output when the turbines are offline for maintenance.

As part of the project requirements, a Preliminary Hazard Analysis (PHA) is required.

The risks associated with the proposed modifications at the Shoalhaven Starches Bomaderry site have been assessed and compared against the Department of Planning risk criteria.

The results presented in this report show compliance with all risk criteria.

Societal risk, area cumulative risk and environmental risk are also concluded to be acceptable.

The primary reason for the low risk levels from the modifications is the low likelihood of significant pipe failures leading to off-site impact from jet or flash fires, or explosions.

Based on the analysis in this PHA, the following recommendations are made:

1. Provide natural gas leak detection in the proposed co-generation plant building with, at least, an alarm in the control room.

2. Provide an actuated valve on the natural gas supply pipe outside of the co-generation plant building for isolation in an emergency.

3. Given the high natural gas pressure in the supply pipeline, class the pipe as a critical pipe and therefore perform routine inspections and integrity checks.

GLOSSARY

ALARP	As Low As Reasonably Practicable
AS	Australian Standard
DoP	NSW Department of Planning
HAZAN	Hazard Analysis
HIPAP	Hazardous Industry Planning Advisory Paper
HRSG	Heat Recovery Steam Generator
HSE UK	Health and Safety Executive United Kingdom
IBC	Intermediate Bulk Container
LEL	Lower Explosive Limit
PHA	Preliminary Hazard Analysis
QRA	Quantitative Risk Assessment
STEL	Short Term Exposure Limit
TLV	Threshold Limit Value

REPORT

1 INTRODUCTION

1.1 BACKGROUND

Shoalhaven Starches is a member of the Manildra Group of companies. The Manildra Group is a wholly Australian owned business and the largest processor of wheat in Australia. It manufactures a wide range of wheat-based products for food and industrial markets both locally and internationally.

The Shoalhaven Starches factory located on Bolong Road, Bomaderry, produces a range of products for the food, beverage, confectionary, paper and motor transport industries including starch, gluten, glucose and ethanol.

Project Approval MP06_0228 for the Shoalhaven Starches Expansion Project made provision for a gas fired co-generation plant that would comprise two natural gas turbine generators that would deliver an anticipated net power output of 40 MW for the site.

Subsequently under Mod 16 the Independent Planning Commission approved an additional coal fired co-generation plant. This coal fired co-generation plant would generate a total of 15 MW of power for the site.

Neither the approved gas nor coal fired co-generation plants have been constructed to date.

Following the original Project Approval, Shoalhaven Starches have obtained approval and/or are seeking approval for a range of modifications to the original Project comprising a range of additional developments that were not envisaged as part of the original Project Approval. Shoalhaven Starches are forecasting that the electrical power load demand created by these and other additional works, subsequent to the original Project Approved development, will exceed the power supply capacity of the approved gas fired and coal fired co-generation plants.

Shoalhaven Starches now propose to construct a new gas-fired co-generation plant which will consist of two natural gas turbines that will generate an anticipated power output each of 30 MW, providing a total power to the site of 60 MW. The new gas fired co-generation plant will replace the approved gas fired and coal fired co-generators. In addition, Shoalhaven Starches also proposed to convert their existing coal fired boilers 2,4, 5 and 6 to gas as well.

The waste heat from each of the gas turbines’ exhausts will be used to generate 11 barg steam in two 110 t/hr heat recovery steam boilers. The boilers will be co-fired with natural gas and will be able to operate at full output when the turbines are offline for maintenance.

As part of the project requirements, a Preliminary Hazard Analysis (PHA) is required.

Shoalhaven Starches requested that Pinnacle Risk Management prepare the PHA for the proposed modifications. This 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 1).

1.2 OBJECTIVES

The main aims of this PHA study are to:

- Identify the credible, potential hazardous events associated with the proposed modifications, i.e. the co-generation plant and the associated new plant and equipment, and the conversion of the existing boilers 2,4, 5 and 6 from coal to natural gas;
- 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 2);
- Evaluate the potential for propagation events;
- Review the adequacy of the proposed safeguards to prevent and mitigate the potential hazardous events; and
- Where necessary, submit recommendations to Shoalhaven Starches to ensure that the proposed modifications are operated and maintained at acceptable levels of safety and effective safety management systems are used.

1.3 SCOPE

This PHA assesses the credible, potential hazardous events and corresponding risks associated with the Shoalhaven Starches proposed co-generation plant and the associated new plant and equipment and the conversion of the existing boilers 2,4, 5 and 6 from coal to natural gas.

There are no changes to the road or rail transport of Dangerous Goods to or from the site as part of this project. Therefore, transport is not assessed.

1.4 METHODOLOGY

In accordance with the approach recommended by the DoP in HIPAP 6 (Ref 1) 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.

The PHA has been conducted as follows:

- Initially, the proposed modifications and their locations were reviewed to identify credible, potential hazardous events, their causes and consequences. Proposed safeguards were also included in this review;
- As the potential hazardous events are located at a significant distance from other sensitive land users, the consequences of each potential hazardous event were estimated to determine if there are any possible unacceptable off-site impacts;
- Included in the analysis is the risk of propagation between the proposed equipment and the adjacent processes; and
- If adverse off-site impacts could occur, assess the risk levels to check if they are within the criteria in HIPAP 4 (Ref 2).

2 SITE DESCRIPTION

The Shoalhaven Starches factory site is situated on various allotments of land on Bolong Road, Bomaderry, within the City of Shoalhaven (see Figure 1). The factory site, which is located on the south side of Bolong Road on the northern bank of the Shoalhaven River, has an area of approximately 12.5 hectares.

The town of Bomaderry is located approximately 0.5 km to the west of the factory site and the Nowra urban area is situated 2.0 km to the south west of the site. The “Riverview Road” area of the Nowra Township is situated approximately 600 metres immediately opposite the factory site across the Shoalhaven River.

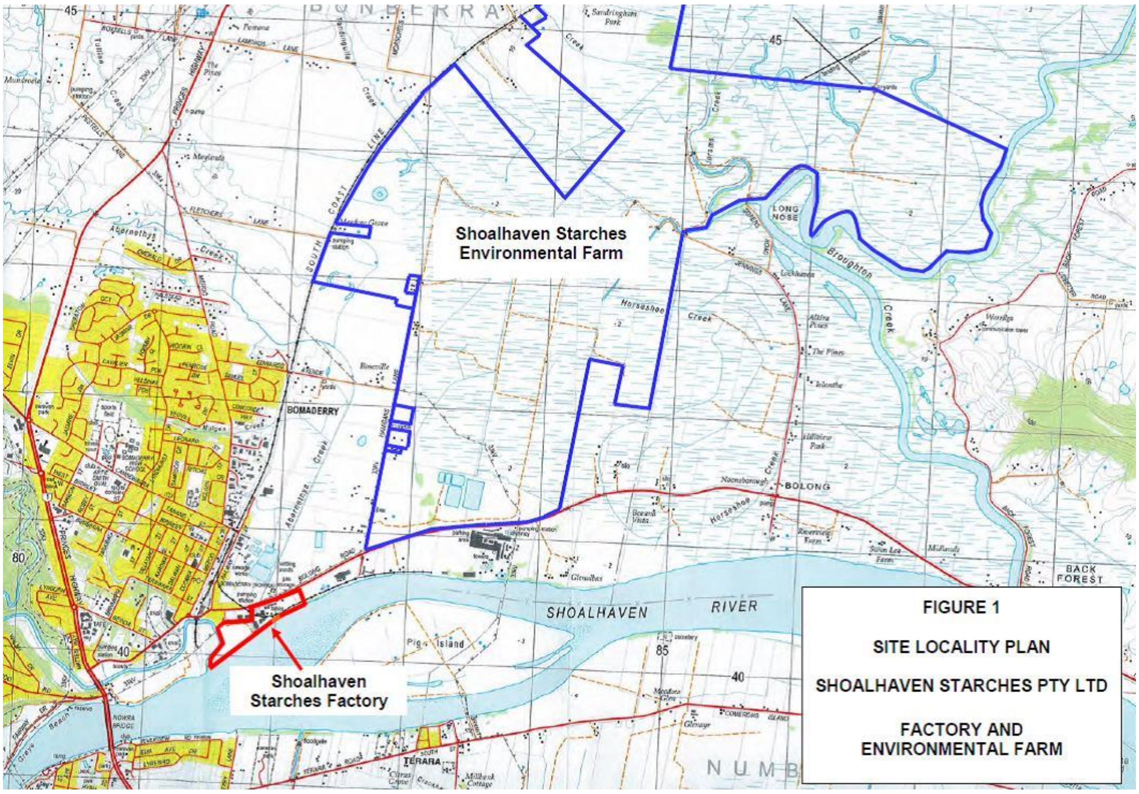
The village of Terara is situated approximately 1.5 kilometres to the south east of the site, across the Shoalhaven River. Pig Island is situated between the factory site and the village of Terara and is currently used for cattle grazing.

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 industrial area is serviced by a privately-owned railway spur line that runs from just north of the Nowra-Bomaderry station via the starch plant and the former Dairy Co-op site to the Paper Mill.

The Company also has an Environmental Farm of approximately 1,000 hectares located on the northern side of Bolong Road. This area is cleared grazing land and contains spray irrigation lines and wet weather storage ponds (total capacity 925 Mega litres). There are at present six wet weather storage ponds on the farm that form part of the waste water management system for the factory. A seventh pond approved in 2002 was converted into the biological section of the new wastewater treatment plant has now been commissioned.

The Environmental Farm covers a broad area of the northern floodplain of the Shoalhaven River, stretching from Bolong Road in the south towards Jaspers Brush in the north. Apart from its use as the Environmental Farm, this broad floodplain area is mainly used for grazing (cattle). The area comprises mainly large rural properties with isolated dwellings although there is a clustering of rural residential development along Jennings Lane (approximately 1 kilometre from the site), Back Forest Road (approximately 500 metres to 1.2 kilometres to the west) and Jaspers Brush Road (approximately 1.2 kilometres to the north).

Figure 1 - Site Locality Plan



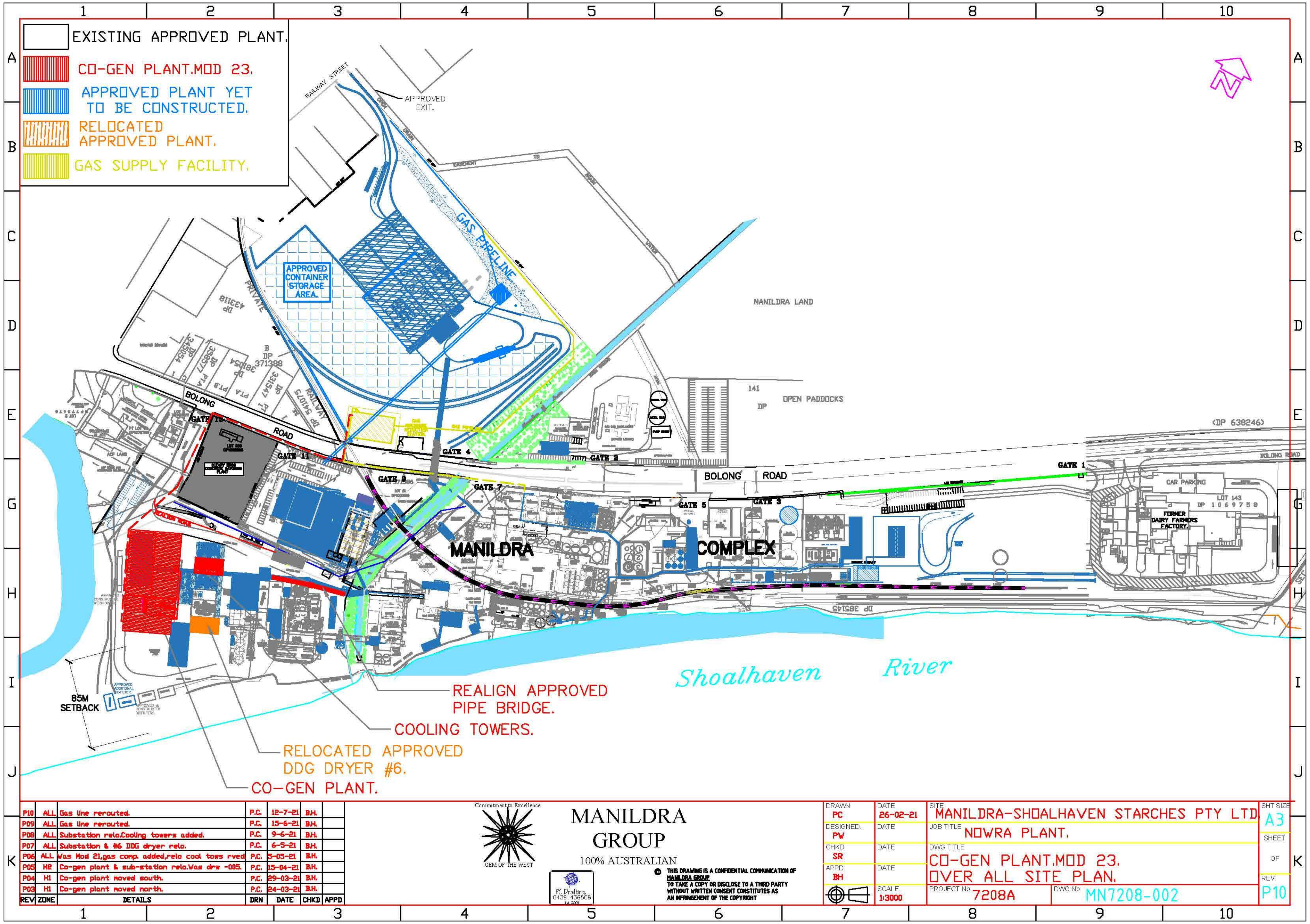
Security of the site is achieved by a number of means. This includes site personnel and security patrols by an external security company (this includes weekends and night patrols). The site operates 7 days per week (24 hours per day). Also, the site is fully fenced and non-operating gates are locked.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

There are approximately 180 people on site during Monday to Fridays 8 am to 5 pm and 100 people on site at other times.

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

A layout drawing showing the proposed location of the modifications is shown in Figure 2.

Figure 2 - Site Layout



3 PROCESS DESCRIPTION

3.1 CO-GENERATION PLANT

3.1.1 Introduction

The new gas fired co-generation plant will be housed within a building that will comprise a structure with a footprint of 2,160 m^2 and a height above ground level of 20.5 metres.

In addition to the above, it is proposed that the existing coal fired boilers 5 and 6 will be fitted with natural gas burners. Consequently, coal will no longer be used on the site following the commissioning of the new and modified plants.

The proposed co-generation plant will be a continuous process based on two natural gas fired turbines, each coupled to a generator capable of generating up to 30MW of power each at 11kV. The power will be connected to the site's main substation for distribution through the existing electrical distribution network.

The exhaust gases from the turbines will be ducted into two heat recovery steam generators (HRSG) which capture the waste heat from the exhaust in conjunction with co-firing of natural gas to produce up to 110te/hr of saturated steam per HRSG at 1,100 kPa.

Each HRSG has a stack for emission of the combined exhaust gases from the turbine and HRSG.

The co-generation plant layout is shown in Figure 3. A process flow schematic for the plant is shown in Figure 4.

3.1.2 Natural Gas Supply

Natural gas is supplied to the co-generation plant turbines at 4,000 kPa. The gas is further reduced to 500kPa for supply to the co-firing of the HRSGs. The 4,000 kPa supply line will be a new pipe (nominal diameter of 300 mm) from a new pressure reduction station and flow metering facility at Bolong Road. The pipe will be constructed from Schedule 40 carbon steel.

Under maximum output conditions, natural gas consumption is 12,293 kg/hr for the turbines and 5,455 kg/hr for the HRSGs.

3.1.3 Steam Export to Site

Steam is supplied from the co-generation plant at 1,100kPa and will be transported via a pipebridge to the existing site boiler house for distribution through the existing steam network. The co-generation plant has a total steam capacity of 220 te/hr.

Figure 3 – Co-Generation Plant Layout

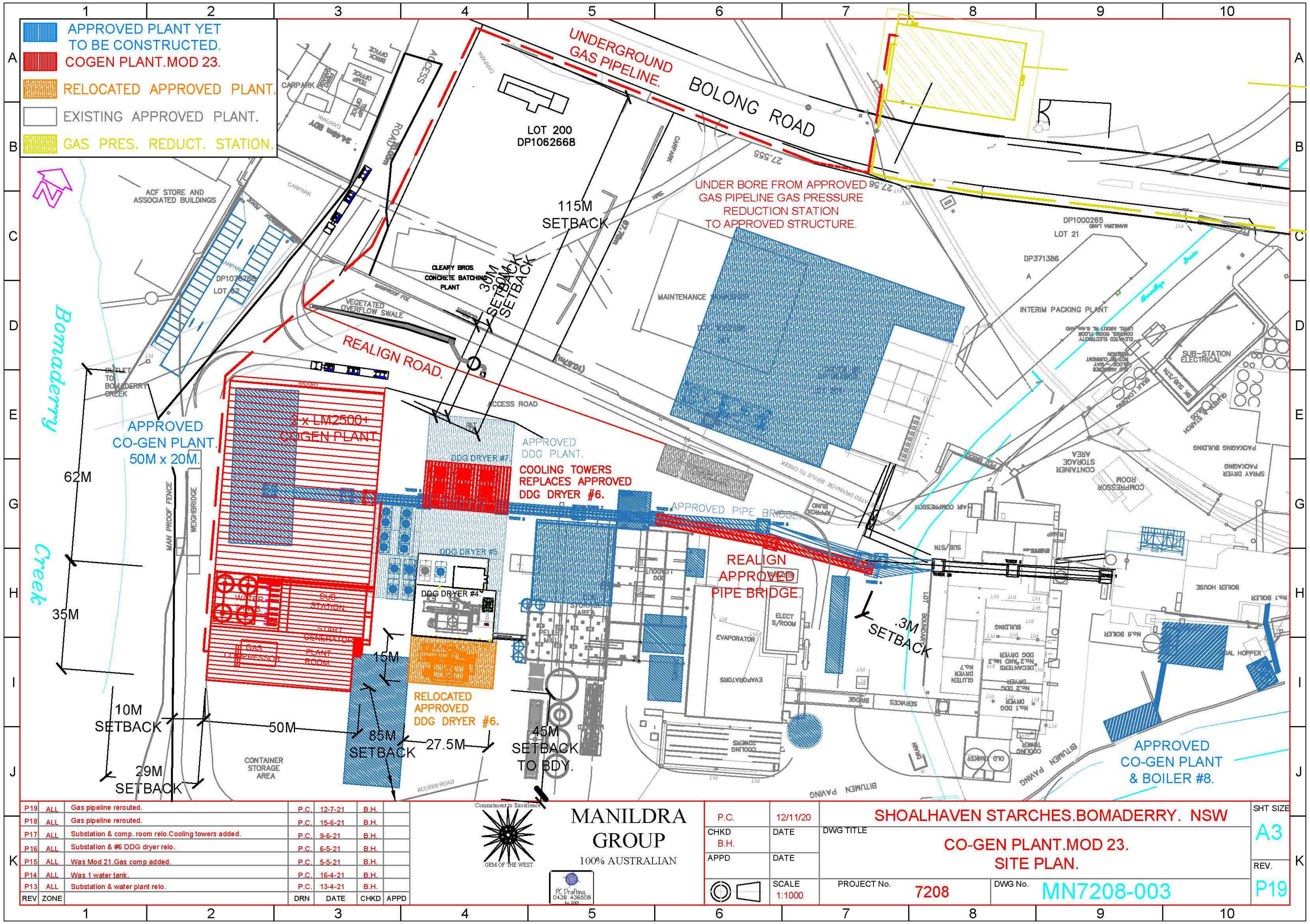
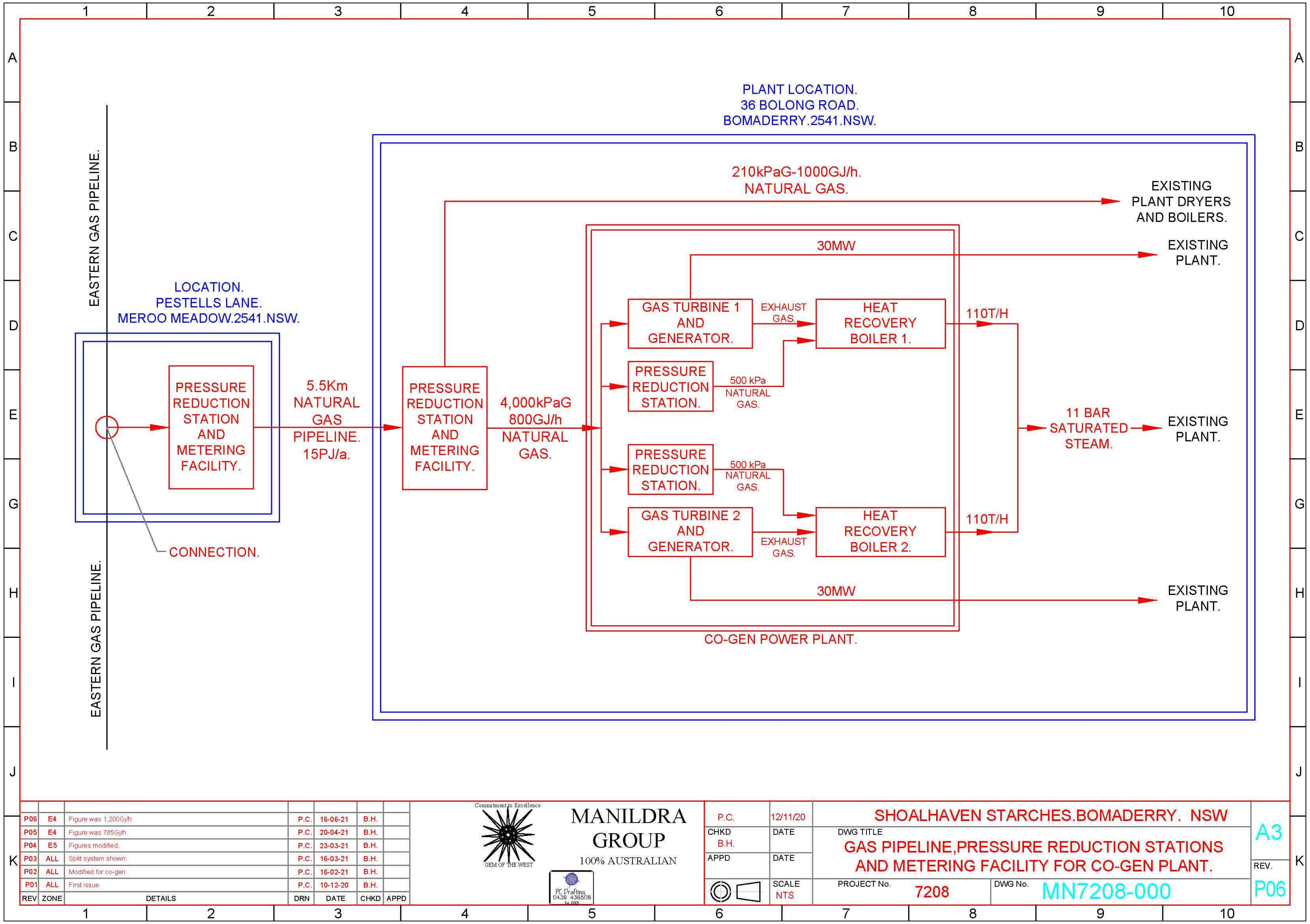


Figure 4 – Co-Generation Plant Process Flow Schematic



3.1.4 Condensate

Condensate is returned from the existing process plant via the boiler house and the pipebridge at 100°C. This return stream provides 70% of the water requirements for the operation of the HRSGs. Condensate is returned directly to the deaerators of the HRSGs.

3.1.5 Make-Up Water

Make-up water is supplied at ambient temperature from the boiler house via the pipebridge and provides the remainder of the water supply required for operation of the HRSGs. A 250m^3 make-up water storage, equivalent to approximately 4 hours of make-up water supply, will be installed at the co-generation plant. The make-up water is preheated prior to supply to the deaerators.

3.1.6 Electricity Supply

Power is supplied from the co-generation plant at 11kV and will be reticulated via cabling on the pipebridge to the existing main substation for distribution through the existing electricity network. The co-generation plant has a capacity of 60MW.

3.1.7 Electricity Supply - Synchronization

The generators will be connected in parallel with the external electricity supply network. To prevent a catastrophic failure of the electrical infrastructure, the generators must be "in phase" with the network prior to connection in a process known as synchronization. The generator control system adjusts the throttle of the turbine to correct the frequency and phase of the generator and adjusts the excitation voltage of the generator to correct the voltage output, such that these values correspond with the external supply. Prior to the closing of a critical circuit breaker, a "check sync" protection relay on the circuit breaker compares the frequency and phase across the circuit breaker to allow closing of the circuit breaker.

3.1.8 Electricity Supply – Reverse Power Protection

To prevent the export of power from the Shoalhaven Starches co-generation plant to the off-site grid, a protection scheme will be provided to monitor the direction of power flow and will trip the incoming supply circuit breakers on detection of any export. The setting of the reverse power protection scheme will be determined in consultation with the local supply authority.

3.1.9 Automatic Control

Automatic control of the co-generation plant will be via a vendor supplied control system comprising Woodward Micronet+ controllers and MARK VIe sequencers. Turbine combustion control is achieved by modulation of an electronically controlled fuel metering valve that adjusts the fuel supply to the turbine. The fuel is mixed with the air flowing through the turbine before ignition in the combustor section. The Micronet+ controller monitors the combustion process for abnormal conditions and initiates pre-determined control actions including trip of the turbine.. Safety Integrity Systems (i.e. SIL rated) will be supplied by MARK VIe.

3.2 GAS-FIRED BOILERS 2,4, 5 AND 6 MODIFICATIONS

Boilers 2, 4, 5 and 6 are currently fired on coal and will be converted to fire on natural gas to achieve the same capacity output. The boilers will only operate as required.

The gas supply will be connected to the existing reticulation system at a supply pressure of 210 kPa. The pressure will be reduced at each burner valve train.

The gas pipework reticulation, valve train, burner and controls will be in accordance with the current AS4041, AS3814 and AS2593 standards, or any other relevant standard.

The following table summaries the natural gas and air flows to boilers 2, 4, 5 and 6.

Table 1 – Boilers Gas and Air Flows

	Gas Flow, GJ/hr	Gas Flow, kg/hr	Air Flow, m^3/hr
Boiler 2	35	740	12,000
Boiler 4	56	1,200	19,500
Boiler 5	119	2,530	40,000
Boiler 6	175	3,710	59,000

Boilers 5 and 6 are fitted with economizers which reduce the flue gas temperatures to 170ºC.

The conversion will include insulating of the existing coal grate and leaving the existing induced draught fan to assist in removal of flue products to the stack. New combustion air fans will be installed to suit the new burners.

The boilers' front plates will be modified to take the new gas burners.

New electrical controls will be included to operate the boiler automatically as per AS2593.

The boilers will have full time boiler attendants and they will perform the relevant checks as per the current Work-Safe code. The boiler attendants will be ticketed with advanced boiler licenses.

4 HAZARD IDENTIFICATION

4.1 HAZARDOUS MATERIALS

The hazardous materials involved with the modifications are:

- Natural gas; and
- Boiler feed water dosing chemicals.

Natural Gas:

Natural gas is flammable, i.e. if released and ignited, there is a risk of jet fires, flash fires and explosions (if confined).

Natural gas is a Class 2.1 Dangerous Good (DG), i.e. a flammable gas.

Natural gas is a colourless hydrocarbon fluid mainly composed of the following hydrocarbons:

- Methane (typically 88.5% or higher);
- Ethane (typically 8%);
- Propane (typically 0.2%);
- Carbon dioxide (typically 2%); and
- Nitrogen (typically 1.3%).

For a typical natural gas, the TLV (threshold limit value) is approximately 1,000 ppm and the STEL (short term exposure limit) is 30,000 ppm (i.e. approaching 5 vol% which is the lower explosive limit).

The hydrocarbons are not considered to represent a significant environmental threat. Their hazard potential derives solely from the fact that they are flammable materials.

To enable ready leak detection, natural gas is normally odorised with mercaptans (sulphur containing hydrocarbons).

The flammability range is typically 5% to 15% v/v in air. The vapours are lighter than air and will normally disperse safely if not confined and/or ignited.

Products of combustion include carbon monoxide and carbon dioxide.

Boiler Feed Water Dosing Chemicals:

The same boiler feed water dosing chemicals that are currently used at the site are to be used for the co-generation plant, i.e.:

- Amercor 8548 – Corrosion inhibitor (DG 8 – corrosive amine liquid) ;
- Amertrol HT 3510 – Deposit inhibitor (DG 8 - 3 to 5% caustic soda);
- Amersite 2 – Oxygen scavenger (DG 8); and
- Antispumin WC 5030 – Antifoam (non-DG).

The storage volumes are relatively small, e.g. IBC's (intermediate bulk containers) or drums, and these will be stored within dedicated bunds to avoid any losses of containment impacting the environment or people. The dosing chemicals will be located adjacent to the HRSGs. Given the relatively small volumes and that all containers are separately bunded then no further analysis of these materials is warranted.

4.2 Potential Hazardous Incidents Review

In accordance with the requirements of *Guidelines for Hazard Analysis*, (Ref 1), 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, "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 (in particular, with the potential for off-site impacts) for the proposed modifications are summarised in the Hazard Identification Word Diagram following (Table 2).

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.

Table 2 – Hazard Identification Word Diagram

Event Number	Hazardous Event	Causes	Consequences	Existing Safeguards - Prevention Detection Mitigation
1	Natural gas explosion within the turbines or boilers 5 and 6	Natural gas flow into the turbines or boilers when the burners are offline	Buildup of natural gas in the turbines' systems or furnaces. If ignited, there is the potential for an internal explosion, i.e. damage to the turbines' systems or boilers. This is a local event and does not pose any credible off-site risks as the co-generation plant will be approximately 160 m from the nearest site boundary (Bolong Road)	Burner management system will be certified to Australian Standards which will include the need for redundant actuated natural gas isolation and air purging prior to startup
2	Loss of containment of natural gas from the supply pipes (outside the co-generation plant building or to boilers 5 and 6)	Pipe failure, e.g. corrosion or weld defect, gasket failure, valve leak, impact	If ignited, potential for a jet fire, flash fire or explosion (if confined) which can impact personnel and equipment	The pipes are to be protected from impact by locating them in piperacks. Minimum flanges used. Pipes to be included in the hazardous zone study. Remote isolation of the natural gas is possible at the gas metering station. The natural gas supply pipe is to be pressure tested following construction and protected against corrosion by painting. The natural gas piping and equipment items are to be compliant with the Australian Standards

Event Number	Hazardous Event	Causes	Consequences	Existing Safeguards - Prevention Detection Mitigation
3	Loss of containment of natural gas from the pipes within the co-generation plant building	Pipe failure, e.g. corrosion or weld defect, gasket failure, valve leak or hose failure	If ignited, there is the potential for an internal building explosion, i.e. damage to the building and equipment as well as the potential for injury to personnel. This is a local event and does not pose any credible off-site risks as the co-generation plant will be approximately 160 m from the nearest site boundary (Bolong Road)	The natural gas supply pipe is to be pressure tested following construction and protected against corrosion by painting. The natural gas piping and equipment items are to be compliant with the Australian Standards. Routine pipe inspections and maintenance
4	HRSG or boiler rupture	Low level, loss of boiler feed water pumps, high factory demand for steam, failure of the level control, control valve stuck closed, low level in feedwater tank	Catastrophic failure of the HRSG or boiler, i.e. equipment damage and injury to on-site personnel when steam and hot condensate is released externally to the boiler, i.e. local event only	Australian Standard compliant low level protection, standby boiler feed water pumps, low and low-low level alarms, boiler trip on low-low level, maintenance on the valves and instruments, low level alarm and trip on the feedwater tank, operator checks on the boiler and feedwater tank sight glass
5	HRSG or boiler rupture	Corrosion, e.g. poor boiler feed water chemistry. Erosion, e.g. from two phase flow	Catastrophic failure of the HRSG or boiler, i.e. equipment damage and injury to on-site personnel when steam and hot condensate is released externally to the boiler, i.e. local event only	Water softeners on the boiler feedwater supply, daily sampling, pH and total dissolved solids checks, routine equipment inspections (weekly, monthly and yearly)

Event Number	Hazardous Event	Causes	Consequences	Existing Safeguards - Prevention Detection Mitigation
6	Failure of the steam drum or high pressure piping	Corrosion (e.g. under lagging corrosion), weld defect, safety relief valves stuck closed, failure of letdown valves	Catastrophic failure of the steam drum or piping, i.e. equipment damage and injury to on-site personnel from a release of steam and possible projectiles	Routine inspections (piping and equipment), operator inspections, operator training (boiler emergency procedure to delay the re-introduction of water following a low-low water level event), redundant safety relief valves, certifications on equipment, high pressure alarm for operator response

5 RISK ANALYSIS

The assessment of risks to both the public as well as to operating personnel around the proposed modifications requires the application of the basic steps outlined in Section 1. As per HIPAP 6 (Ref 1), the chosen analysis technique should be commensurate with the nature of the risks involved. Risk analysis could be qualitative, semi-quantitative or quantitative.

The typical risk analysis methodology attempts to take account of all credible hazardous situations that may arise from the operation of processing plants etc.

Having identified all credible, significant incidents, risk analysis requires the following general approach for individual incidents:

Risk = Likelihood x Consequence

The risks from all individual potential events are then summated to get cumulative risk.

For QRA (quantitative risk analysis) 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 distances from the proposed modifications to residential and other sensitive land users are large and hence it is unlikely that any significant consequential impacts, e.g. due to radiant heat from fires, from the facility will have any significant contribution to off-site risk.

The risk criteria applying to developments in NSW are summarised in Table 3 on the following page (from Ref 2).

Table 3 - 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

As discussed above, the consequences of the potential hazardous events are initially analysed to determine if any events have the potential to contribute to the above-listed criteria and hence worthy of further analysis. The potential hazardous events of interest in this PHA are jet and flash fires, and vapour explosions.

5.1 Natural Gas Releases – Jet Fires Consequences

Releases from the natural gas piping systems can be ignited. The natural gas pressure throughout the site is 210 kPag, i.e. this is the pressure within the supply natural gas piping to the boilers. The pressure within the new piping to the co-generation plant is 4,000 kPag. As the natural gas supply pressures to the boilers and the co-generation plant are different then separate models for jet fires are detailed below.

The analysis of potential jet fires for the natural gas piping for the boilers is shown in Table 4. The mass rates, flame length and radiant heat were estimated using TNO's EFFECTS program. The new pipe diameter is 450 mm.

Table 4 – Natural Gas Jet Fires – Boilers

Stream	Estimated Release Rate, kg/s	Estimated Length of Jet, m	Distance (m) to 12.kW/m^2
Full bore failure (450 mm)	5.9	36	44
50 mm hole	0.64	13	14

Notes:
1. Jet flames modelled using methane.
2. Full bore rate limited by upstream supply valving, i.e. 21,200 kg/hr = 5.9 kg/s
3. 13 mm hole size not included given low flows and small potential jet lengths
4. Distance to 12.6 kW/m2 is for a worst-case horizontal jet fire

Adverse off-site impact from potential jet fires from the boilers' new supply pipe is possible if the failure was to occur close to Bolong Road. Based on the modelling, the distance to 4.7 kW/m^2 from a catastrophic pipe failure is up to 75 m (i.e. for a worst-case horizontal jet fire; significantly less for a vertical jet). Given the separation distances to the nearest residential areas exceed 75 m then no adverse impact is expected to these receptors.

If a worst-case horizontal jet is assumed then the distance to 12.6 kW/m^2 (i.e. potential for fatality from radiant heat for a 20 second exposure) is approximately 44 m (for a catastrophic pipe failure). Correspondingly, if the new boilers natural gas supply pipe fails within approximately 44 m of Bolong Road then adverse off-site impact could occur. This scenario is therefore analysed further in Section 5.3.

The analysis of potential jet fires for the natural gas piping to the co-generation plant is shown in Table 5. The mass rates, flame length and radiant heat were again estimated using TNO's EFFECTS program. The new pipe diameter is 300 mm.

Table 5 – Natural Gas Jet Fires – Co-Generation Plant

Stream	Estimated Release Rate, kg/s	Estimated Length of Jet, m	Distance (m) to 12.kW/m^2
Full bore failure (300 mm)	4.7 (Note 1)	29	29
50 mm hole	4.7 (Note 1)	29	29
13 mm hole	0.57	11	-

Notes: 1. Full bore rate limited by upstream supply valving, i.e. 16,960 kg/hr = 4.7 kg/s.

2. Jet flames modelled using methane.

If a worst-case horizontal jet is assumed then the distance to 12.6 kW/m^2 (i.e. potential for fatality from radiant heat for a 20 second exposure) is approximately 29 m (a vertical jet poses significantly less radiant heat for the same release scenario). Correspondingly, if the new co-generation plant natural gas supply pipe fails within approximately 29 m of Bolong Road then adverse off-site impact could occur. This scenario is therefore analysed further in Section 5.3.

5.2 Natural Gas Releases – Flash Fires and Explosions Consequences

Potential flash fires and vapour cloud explosions can occur from natural gas pipe failures and delayed ignition.

For flash fires, any person inside the flash fire cloud is assumed to be fatally injured. As flash fires are of limited duration (typically burning velocity is 1 m/s, Ref 3) then those outside the flash fire cloud have a high probability of survival without serious injury.

The effects from explosion overpressures (Ref 2) are summarised in Table 6.

Table 6 – Effects of Explosion Overpressure

OVERPRESSURE, kPa	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

OVERPRESSURE, kPa	PHYSICAL EFFECT
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

The analysis of the potential flash fires and vapour cloud explosions from the natural gas pipe failures is shown in Table 7. The mass calculated in the flammable range is assumed to be 50% confined, i.e. the area where the releases can occur that can lead to off-site impact are not highly congested. As methane is not a highly reactive flammable gas and the quantities involved are relatively small then a medium deflagration (Curve 5) is assumed in the explosion calculations (multi-energy method – TNO).

Table 7 - Natural Gas Flash Fires and Vapour Cloud Explosions

Stream	Mass of Natural Gas in the Flammable Range, kg	Radius of Flash Fire, m	Distance (m) to 14 kPa Explosion Overpressure	Distance (m) to 7 kPa Explosion Overpressure
Boilers and Dryers Natural Gas Supply:				
Full bore failure (450 mm)	563	120 m	45 m	91 m
50 mm hole	9	19 m	5 m	23 m
Co-Generation Plant Natural Gas Supply:				
Full bore failure (300 mm) and 50 mm hole	378	100 m	39 m	79 m

Notes: 1. Pipeline failures assumed to be isolated within 5 minutes.

2. Radius of flash fires calculated to be the distance to LEL (lower explosion limit) at F weather stability and 1.5 m/s wind speed.

3. 13 mm holes are not modelled as they are too small to generate gas clouds of any significant size.

4. Overpressure distances are from the centre of the gas cloud

For the gas modelling, steady state conditions are reached soon after the release occurs, i.e. after approximately 2 minutes, therefore the distance to the LEL does not change at steady state dispersion conditions.

Given the modelling results in Table 7, if the new boilers and co-generation plant natural gas supply pipes fail within approximately 120 m and 100 m, respectively, of Bolong Road then adverse off-site impact (i.e. potential fatality) could occur. The likelihood and risk for these events are assessed in the following section.

5.3 LIKELIHOOD AND RISK ANALYSIS

Adverse off-site impact (i.e. potential fatality) is possible from releases from the natural gas supply pipes (full bore and/or 50 mm holes) that can lead to jet fires, flash fires and vapour cloud explosions.

The probability of ignition of flammable gas releases from gas pipelines is provided in AS2885.6 Table F2. For a large release rate from a pipeline of DN≤400 (i.e. the supply pipe to the Cogeneration Plant), the ignition probability is 0.1. For a pipeline >DN400 (i.e. the boilers supply pipe), the ignition probability is 0.3. However, in this PHA, the ignition probability for both pipelines is assumed to be 30% (i.e. conservative).

The low likelihoods for potential pipeline failures are supported by the following data (Ref: UK HSE (Ref 4). This data is used in the following risk analysis.

Table 8 – Piping Failure Frequencies

Failure Rates (per m per year) for Pipework Diameter (mm)					
Hole Size:	**0 - 49**	**50 - 149**	**150 - 299**	**300 - 499**	**500 – 1,000**
3 mm diameter	1×10^{-5}	2×10^{-6}			
4 mm diameter			1×10^{-6}	8×10^{-7}	7×10^{-7}
25 mm diameter	5×10^{-6}	1×10^{-6}	7×10^{-7}	5×10^{-7}	4×10^{-7}
1/3 pipework diameter			4×10^{-7}	2×10^{-7}	1×10^{-7}
Guillotine	1×10^{-6}	5×10^{-7}	2×10^{-7}	7×10^{-8}	4×10^{-8}

The pipelines' risk analysis is presented in Table 9. The following notes apply to this conservative, simplified approach.

- The likelihood for 50 mm holes is taken to be the same as 25 mm holes (as data for 50 mm holes is not provided by the HSE). Typically, the likelihood of occurrence for a larger hole size will be lower than that for a smaller hole size.

- The pipeline distances correlate to the F1.5 modelled. In practice, these distances will be lower for the other, more unstable weather/wind conditions. The typical weather/wind data for the site is shown in Appendix A.

- The pipeline distances are to 12.6 kW/m^2 and 14 kPa, i.e. to show that individual fatality risk of 50 pmpy remains within the site's boundary.

The simplified risk analysis shows that the individual fatality risk at the site's boundary will be no higher than 0.5 pmpy for the boilers natural gas supply pipe and 2 pmpy for the co-generation plant natural gas supply pipe. As this is less than 50 pmpy then this HIPAP 4 risk criterion is satisfied. As the two pipes enter the site at different locations with a separation distance of approximately 300 m then the results in Table 9 do not need to be summated for cumulative risk estimation.

This is a low level of risk, it is below the risk criteria shown in Table 3 for risk level at a site's boundary and is not considered intolerable. The ALARP (As Low As Reasonably Practicable) principle is achieved; primarily due to compliance with the Australian Standards for piping.

Compliance with the HIPAP 4 risk criteria is shown in Table 10.

Table 9 – Risk Analysis

Release Case:	Probability of Ignition	Probability of Event Type	Likelihood of Failure (times/year.m)	Pipeline Distance for Off-Site Impact (m)	Probability of Wind Direction (from the south)	Individual Fatality Risk Estimate (pmpy)
Boilers:						
Jet Fire - Full Bore Pipe Failure	0.3	0.3	7.00E-08	44	0.15	4.16E-08
Jet Fire - 50 mm Hole	0.3	0.3	5.00E-07	14	0.15	9.45E-08
Flash Fire - Full Bore Pipe Failure	0.3	0.4	7.00E-08	120	0.15	1.51E-07
Flash Fire - 50 mm Hole	0.3	0.4	5.00E-07	19	0.15	1.71E-07
Vapour Explosion - Full Bore	0.3	0.3	7.00E-08	45	0.15	4.25E-08
Vapour Explosion - 50 mm hole	0.3	0.3	5.00E-07	5	0.15	3.38E-08
					Total	**5.35E-07**
Co-Generation Plant:						
Jet Fire - Full Bore Pipe Failure	0.3	0.3	7.00E-08	29	0.15	2.74E-08
Jet Fire - 50 mm Hole	0.3	0.3	5.00E-07	29	0.15	1.96E-07
Flash Fire - Full Bore Pipe Failure	0.3	0.4	7.00E-08	100	0.15	1.26E-07
Flash Fire - 50 mm Hole	0.3	0.4	5.00E-07	100	0.15	9.00E-07
Vapour Explosion - Full Bore	0.3	0.3	7.00E-08	39	0.15	3.69E-08
Vapour Explosion - 50 mm hole	0.3	0.3	5.00E-07	39	0.15	2.63E-07
					Total	**1.55E-06**

Probability of event type from the UKOOA Report (Ref 5).

Table 10 – HIPAP 4 Risk Criteria Compliance

Description	Risk Criteria	Comments	Risk Acceptable?
Fatality risk to sensitive uses, including hospitals, schools, aged care	0.5×10^{-6} per year	No adverse levels of radiant heat or explosion overpressures to impact any of these land users. For example, the nearest residential area is approximately 400 m from the co-generation building	Yes
Fatality risk to residential and hotels	1×10^{-6} per year	No adverse levels of radiant heat or explosion overpressures to impact any of these land users. For example, the nearest residential area is approximately 400 m from the co-generation building	Yes
Fatality risk to commercial areas, including offices, retail centres, warehouses	5×10^{-6} per year	The estimated individual fatality risk at the site boundary is up to 2 pmpy. This is below this criterion	Yes
Fatality risk to sporting complexes and active open spaces	10×10^{-6} per year	The are no sporting complexes or active open spaces where adverse levels of radiant heat or explosion overpressures are expected	Yes
Fatality risk to be contained within the boundary of an industrial site	50×10^{-6} per year	The estimated risk at the site boundary is up to 2 pmpy. This is below this criterion	Yes
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	No adverse levels of radiant heat or explosion overpressures to impact any residential areas. For example, the nearest residential area is approximately 400 m from the co-generation building	Yes

Description	Risk Criteria	Comments	Risk Acceptable?
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	No toxic gases associated with this modification	Yes
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	No toxic gases associated with this modification	Yes
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	As the estimated individual fatality risk at the site boundary is up to 2 pmpy then this criterion is satisfied	Yes

5.4 PROPAGATION AND CUMULATIVE RISK

There are design and safety management system controls (summarised in Table 2) that are designed to prevent hazardous events occurring. These include designing to Australian and international standards and codes, hazardous area assessments, and controls on ignition sources, e.g. permits to work. Should these prevention controls fail and an incident occur then propagation is possible for some events, e.g. due to radiant heat from jet or flash fires, or explosion overpressures.

Propagation from potential natural gas releases is a low likelihood, e.g. the low pipe failure likelihoods in Table 8 and the low risk levels detailed in Table 9. Compliance and certification to the boiler codes ensures the risk of incidents achieves ALARP.

Correspondingly, it is reasonable to conclude that the proposed modifications do not make a significant contribution to the existing cumulative risk in the area.

5.5 SOCIETAL RISK

The criteria in HIPAP 4 for individual risk do not necessarily reflect the overall risk associated with any proposal. In some cases, for instance, where the 1 pmpy contour approaches closely to residential areas or sensitive land uses, the potential may exist for multiple fatalities as the result of a single accident. One attempt to make comparative assessments of such cases involves the calculation of 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.

In this study of the modified Shoalhaven Starches site, the risk of off-site fatality is below the HIPAP 4 risk criteria. As the nearest house is approximately 400 m away and the low likelihoods for pipe failures, the concept of societal risk applying to populated areas is therefore not applicable for this project.

5.6 RISK TO THE BIOPHYSICAL ENVIRONMENT

The main concern for risk to the biophysical environment is generally with effects on whole systems or populations. For the proposed modifications involving natural gas, steam, boiler feedwater and power, there are no solid, liquid or gaseous effluents that could significantly impact the environment.

Whereas any adverse effect on the environment is obviously undesirable, the results of this study show that the risk of losses of containment is broadly acceptable.

6 CONCLUSION AND RECOMMENDATIONS

The risks associated with the proposed modifications at the Shoalhaven Starches Bomaderry site have been assessed and compared against the DoP risk criteria.

The results presented in this report show compliance with all risk criteria.

Societal risk, area cumulative risk and environmental risk are also concluded to be acceptable.

The primary reason for the low risk levels from the modifications is the low likelihood of significant pipe failures leading to off-site impact from jet or flash fires, or explosions.

Based on the analysis in this PHA, the following recommendations are made:

1. Provide natural gas leak detection in the proposed co-generation plant building with, at least, an alarm in the control room.

2. Provide an actuated valve on the natural gas supply pipe outside of the co-generation plant building for isolation in an emergency.

3. Given the high natural gas pressure in the supply pipeline, class the pipe as a critical pipe and therefore perform routine inspections and integrity checks.

7 APPENDIX A – METEOROLOGICAL DATA

Appendix A - 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.

Wind Direction	Stability Class / Wind Speed (m/s) 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	

8 REFERENCES

1 Department of Planning and Infrastructure (NSW) *Hazardous Industry Planning Advisory Paper No 6 – Hazard Analysis,* January, 2011

2 Department of Planning and Infrastructure (NSW) *Hazardous Industry Planning Advisory Paper No 4 – Risk Criteria for Land Use Safety Planning,* January, 2011

3 ICI HAZAN Course Manual, 1997

4 UK HSE, *Failure Rate and Event Data for use within Risk Assessments*, 28/06/2012

5 UKOOA, *IP Research Report, Ignition Probability Review, Model Development and Look-Up Correlations*, January 2006