VOC EMISSION MANAGEMENT PLAN

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Shoalhaven Starches (Ethanol) – Bomaderry

Assured Environmental

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Table 1: History of Revisions

Revision	Date	Issued to	Changes
R0	26/08/2021	N. Arya	Initial Release.
R1	6/09/2021	N. Arya	Comments addressed.
R2	01/11/2021	N. Arya	Comments addressed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

°C	Degrees Celsius.
Am^3/hr	Cubic metres per hour during actual operating conditions.
$g/m^3/hr$	Grams per cubic metre per hour.
K	Kelvin, temperature. 0°C is equal to 273.15 K.
kg	Kilogram.
km	Kilometre.
kPa	Kilopascal, 1000 pascals.
LEL	Lower explosive limit.
m	Metre.
m^3	Cubic metre.
m^3/hr	Cubic metres per hour.
m^3/sec	Cubic metres per second.
mg	Milligrams.
mg/L	Milligrams per litre.
mg/m^3	Milligrams (10-3) per cubic metre. Conversions from mg/m3 to parts per volume concentrations (i.e., ppm) are calculated at 0 °C.
$mg/m^3/hr$	Milligrams per cubic metre per hour.
ML	Megalitres.
Nm^3/hr	Cubic metres per hour during normal operating conditions.
N_2	Nitrogen.
NO_x	Nitrogen oxides.
p.a.	Per Annum.
Pa	Pascal, pressure.
PBT	Packed bed tower.
POEO	Protection of the Environment Operations.
ppb	Parts per billion.
ppm	Parts per million.
Sm^3/sec	Standard cubic metre per second.
SO_x	Sulphur oxides.
SWSI	Single width single inlet.
VDU	Vapour Destruction Unit.
VRU	Vapour Recovery Unit.
VOC	Volatile Organic Compound.
VOC-MP	VOC Management Plan
%	Percent.
<	Less than.
>	More than.

1 INTRODUCTION

1.1 Background

Shoalhaven Starches (Ethanol) produces a range of products including wheat flours, bakery mixes, wheat gluten and proteins, starches, syrups, stock feeds, fats and oils, bagging, and ethanol. With many uses including foods and beverages, industrial uses, and transport fuels, ethanol is also the primary ingredient in hand sanitiser. Recently there has been a large increase in the need for hand sanitiser and Beverage Grade Ethanol, and to meet this demand, Shoalhaven Starches are expanding their ethanol processing and storage capabilities.

Shoalhaven Starches Expansion Project Modification 19 propose three new ethanol storage tanks to be constructed at the Shoalhaven Starches site at 160 Bolong Road, Bomaderry ('the premises'). The modification was approved by the Department of Planning, Industry and Environment on 8 March 2021.

As a part of the approved development consent, Shoalhaven Starches is required to develop a Volatile Organic Compound ('VOC') (ethanol) Emission Management Plan.

Condition 9J of the consent states:

Prior to the construction of the ethanol storage tanks as described in MOD 19, the Applicant must prepare a VOC (ethanol) emission management plan in consultation with the EPA and to the satisfaction of the Planning Secretary. The measures detailed in the management plan are to be implemented prior to commissioning of the ethanol storage tanks.

1.2 Scope of Works

Assured Environmental (AE) have been appointed by Total Air Pollution Control (TAPC) to develop a VOC management plan for the expansion of Shoalhaven Starches (Ethanol) Storage Facility in Bomaderry, New South Wales (NSW).

The management plan is seeking to demonstrate that the proposed storage tanks will be designed to minimise VOCs emissions. In this regard, the management plan comprises:

- Detailed characterisation of the emissions from the tanks.
- A detailed review of all feasible and reasonable mitigation measures available for this type of tank and industry (i.e., best practice).
- Benchmarking the proposed controls to be implemented against best practice. This must include but is not limited to include robust information to describe efficiency in emission reduction and the appropriateness for the operations.
- Detailed justification with supporting evidence for any identified best practice mitigation measures that are not proposed for implementation.

Whilst the EPA currently has no specific guidelines for the preparation of a management plan to control VOC emissions, there is extensive literature for emission controls and mitigation measures from food grade tanks.

2 REGULATORY FRAMEWORK

2.1 Environmental Protection Licence 883

Environmental Protection License number 883 (dated 1-Jun-2021) provides air emission limits for a number of release points currently across the site, including the gluten dryer baghouse, starch dryer scrubber, carbon dioxide scrubber, treated effluent dams, sulphur oxidisation pond, combined boiler stack, inlet/outlet pipe to biofilters, fermenter and DDG pellet plant stack emission point.

2.2 Protection of the Environment Operations (Clean Air) Regulation 2010

Shoalhaven Starches is a scheduled premise under the Protection of the Environment Operations (POEO) (Clean Air) Regulation 2010; the standard for concentrations relating to VOCs is detailed in Schedule 3 of the Regulation and summarised in Table 2.

Table 2: Standard Concentrations

Air Impurity	Activity or Plant	Standard Concentration
Volatile organic compounds (VOCs), as n-propane equivalent	Any vapour recovery unit Any distillation process	Group 6: 40 mg/m^3, dry, 273 K, 101.3 Pa

2.3 Tank Design Considerations

On 17 June 2021, Shoalhaven Starches wrote to the EPA seeking advice regarding whether there is a VOC limit that Shoalhaven Starches is required to meet. The EPA provided the following guidance:

> *The EPA notes that it does not have detailed information regarding expected emissions from the storage tanks, nor any information regarding their design/capacity. However, it is considered best practice that volatile organic liquids with vapour pressure <75kPa are stored in either floating roof tanks with double seals, or fixed roof tanks that discharge emissions through a vapour recovery unit (VRU) or a vapour destruction unit (VDU). The fixed roof tanks can include nitrogen blanketing if required.*
>
> *The EPA would expect the VRU or VDU be constructed so that the vapour emitted from the tank meets the following:*
>
> *1. VRU: the total concentration of unrecovered vapour emitted to the atmosphere during any period of 4 hours does not exceed 10 milligrams [as n-propane] per litre of volatile organic liquid passing into the tank during that period; or*
>
> *2. VDU: the total concentration of unburnt vapour emitted to the atmosphere has a concentration <40 mg/m^3 as n-propane (assuming the vapours treated do not contain any principal toxic air pollutants)*
>
> *3. Vapours emitted during filling of delivery trucks are also treated by the VRU/VDU*

The EPA reiterates that the above are not "goals to pollute up to" but instead, an indication of what these systems can achieve. Therefore, Shoalhaven Starches should demonstrate that they have evaluated and implemented all practical measures to prevent or minimise (as far as practicable) emissions from this source.

2.4 Summary

Based on the POEO and the guidance from EPA, best practice emissions of VOCs from the storage tanks should be <40 mg/m^3.

3 ENVIRONMENTAL CONSIDERATION

3.1 Location

Figure 1 presents the current landuses surrounding the Facility; the majority of the landuses are industrial in nature, however there are sensitive receptors 500 m to the west of the Facility in the form of local shops and residences, and a caravan park with nearby residences 1000 m to the south.

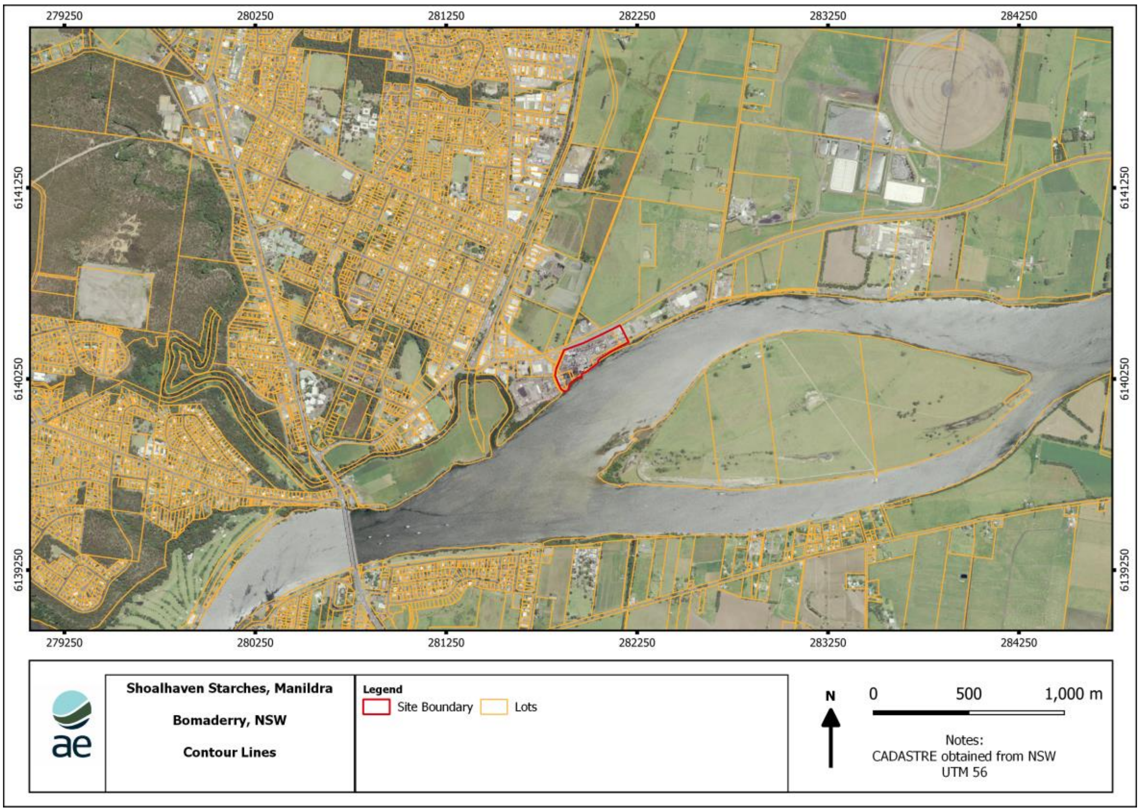

Figure 1: Landuses Surrounding the Facility.

A review of the surrounding area has identified VOC sources from nearby industries - automotive spray painting to the west and a wastewater treatment plant to the north-west. The vapours from both of these uses have a different composition compared to ethanol, therefore the vapour from surrounding facilities is not expected to be cumulative in nature.

3.2 Terrain Conditions

Terrain data for the area surrounding the development was obtained at 10 m intervals. It can be seen in Figure 2 that the area surrounding the Facility is located at 1 to 10 m above sea level with elevations to the north-west and southwest of the Facility. There are lowlands to the east following Shoalhaven River 12 km out to sea, however elevations to the northeast increase sharply to 250 m above sea level.

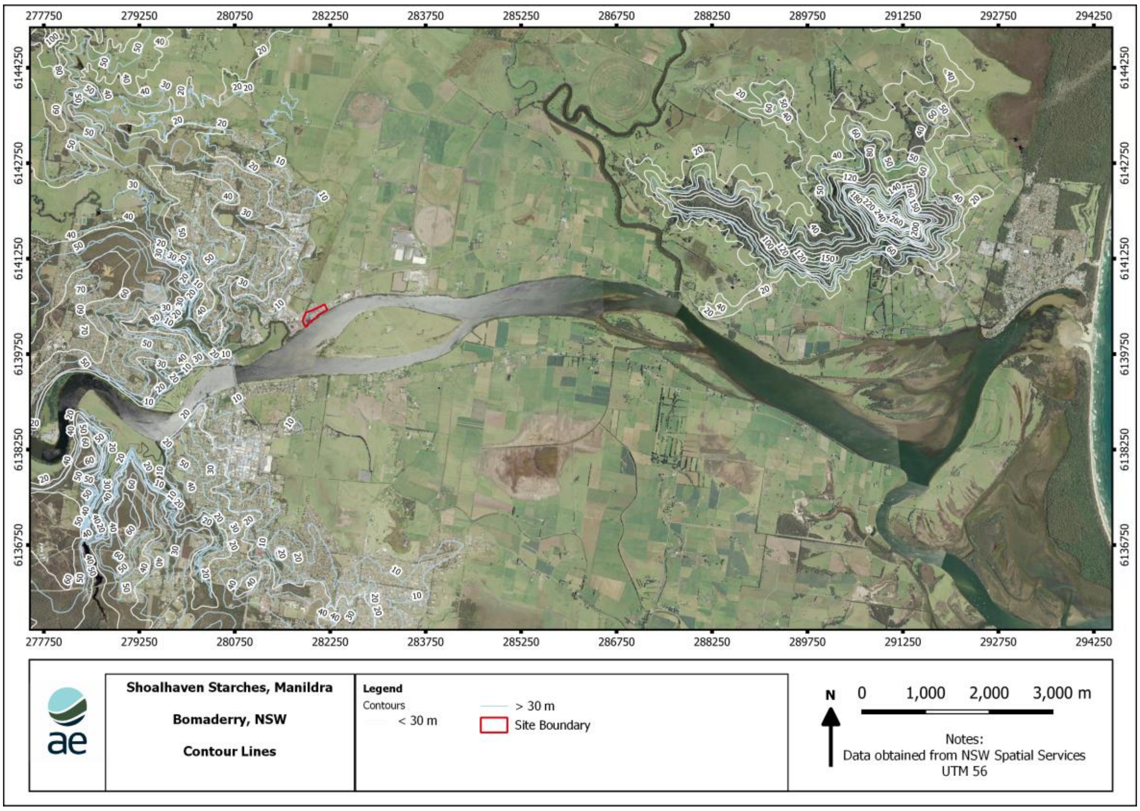

Figure 2: Topography Surrounding the Facility.

During periods of atmospheric stability, typically during the evening, night-time and early morning periods, any VOCs emitted from the Facility are likely to disperse to the east of the Facility due to the similar/lower elevations.

3.3 Meteorological Conditions

Wind roses displaying averaged data over the last 20 years from the BOM automatic weather station in Nowra, Figure 3 below, indicate predominate north-westerly winds at 9 am, and easterly winds at 3 pm.

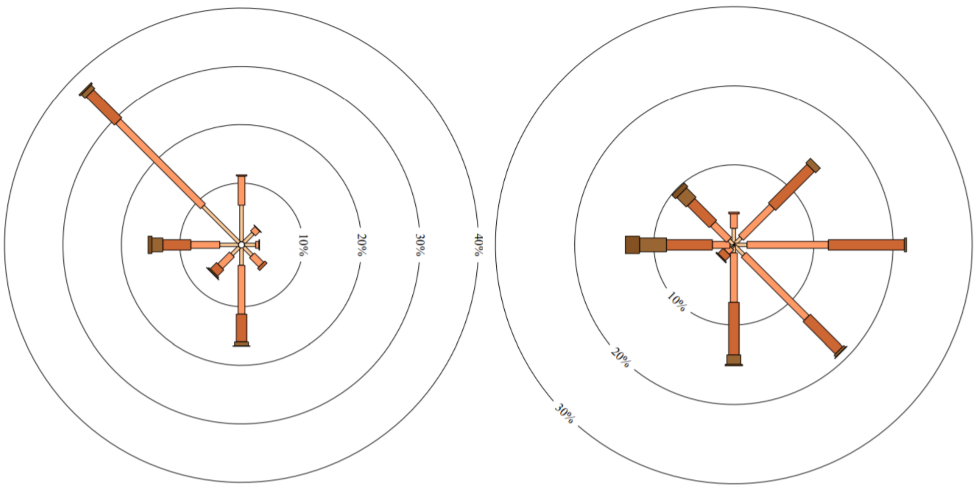

Figure 3: BOM Nowra Wind Roses, 9 am left, 3 pm right

4 EXISTING FACILITY

4.1 Capacity

Shoalhaven Starches current ethanol processing and storage capability comprises fourteen tanks, with a total capacity of 4.32 ML. The layout of the tanks is presented in Figure 4. The tanks shown in blue are associated with MOD 18 and the tanks shows in red are associated with MOD 19.

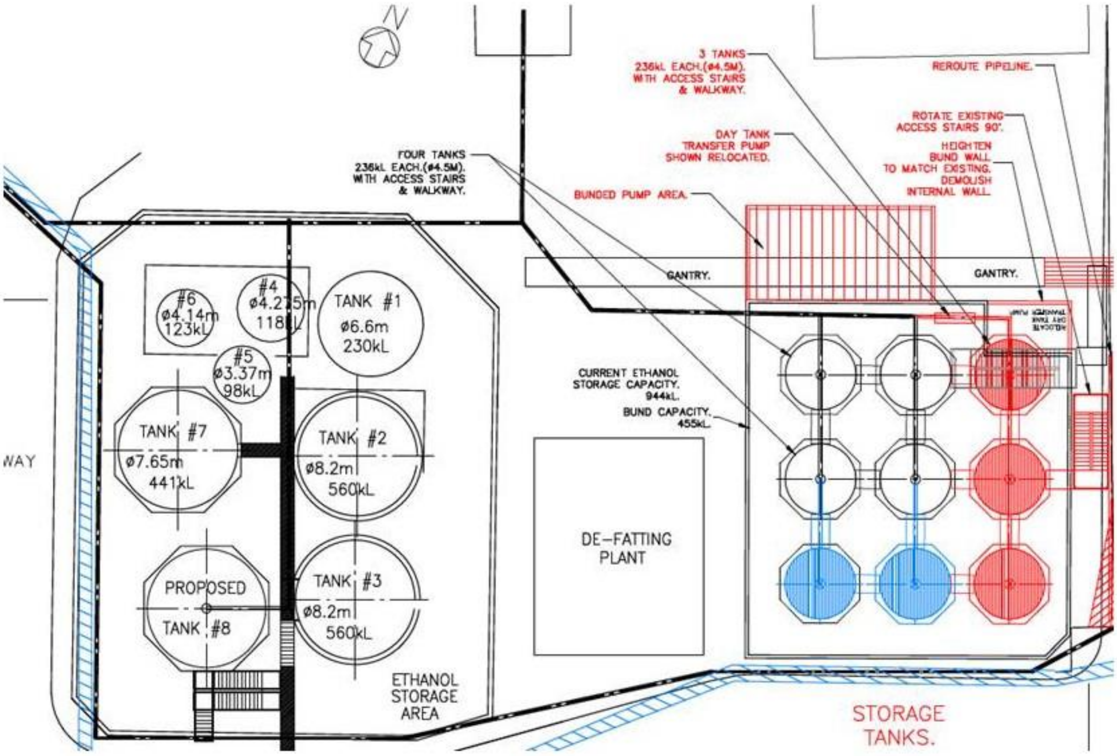

Figure 4: Bomaderry Current Ethanol Storage Location.

Each beverage ethanol tank is fitted with an individual Protectoseal Series 830 combination conservation vent valve and flame arrestor which vents directly to atmosphere during the fill operation. The tanks are also fitted with individual emergency pressure manhole covers (Protectoseal Series 53300) that also vent directly to atmosphere to relieve pressure in the event of an emergency (e.g., Fire). At the moment there is a considerable release of ethanol vapor during the filling of storage tanks.

From the most current available National Pollutant Inventory (NPI) report for financial year 2019 – 2020, total volatile organic compounds at the Shoalhaven Starches (Ethanol) Bomaderry plant (air point + fugitive) were calculated at 35,000 kg across the whole site. As part of TAPCs proposal, they worked with M.E. Engineering (MEENG) to calculate current emission rates of ethanol to atmosphere, based on average conditions with the current system in place. Over the course of 2020, it was calculated that a total of 22,867 kg of ethanol was released to the atmosphere from the current tank arrangement in place.

Installation and use of an industry best-practice VOC mitigation device will greatly reduce VOC emissions from these tanks, ensuring Shoalhaven Starches are in alignment with their sustainability commitments, specifically providing a long-term positive difference to the environment.

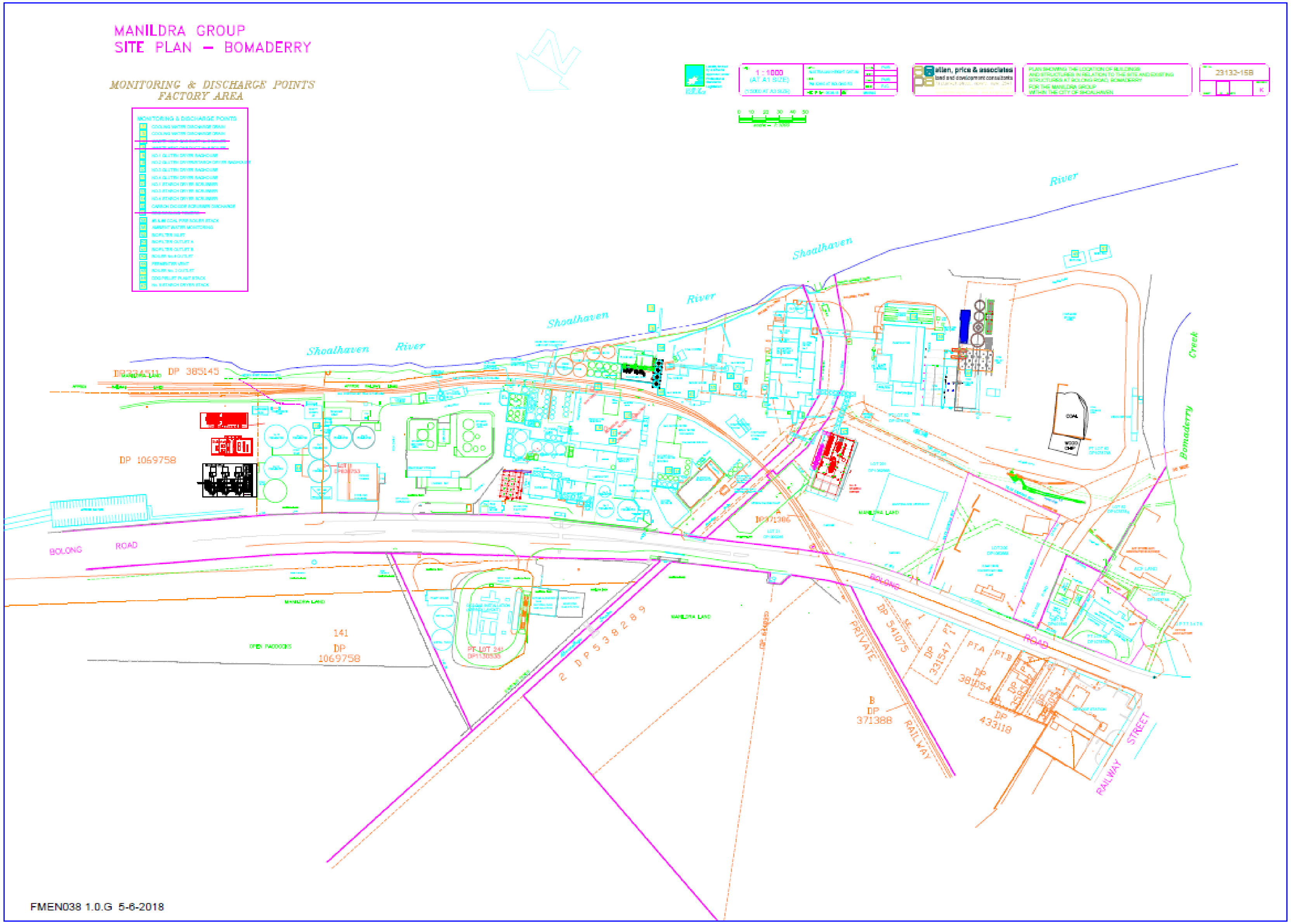

Figure 5: Bomaderry Site Map.

5 DESCRIPTION OF PROPOSED SYSTEM

5.1 Introduction

The proposed plans will increase the storage capacity to sixteen tanks with a total capacity of approximately 4.8 ML as shown in Figure 6.

TAPC is proposing a Vapour Recovery Unit (VRU), a wet scrubbing system connected via ducting to all of the tanks, which will extract the vent gases (N_2 + Ethanol) by absorption with water, removing the ethanol from the gas stream and recovering it in a discharged scrubbing solution. This system involves the installation and use of one unit, based on packed bed scrubbing. The proposed solution takes into account the information and data provided by ME Engineering and Shoalhaven Starches (Ethanol), following TAPC's visit to the site.

The new Beverage Grade Ethanol tank arrangement will be as per the following layout sketch, where 8 x Day Tanks are arranged in the eastern bunded area, and 1 x Storage Tank is transported from the east to the west side bunded area. The remaining tanks currently store fuel and industrial grade ethanol and will not be connected to the VRU due to the risk of cross-contamination with Beverage Grade Ethanol.

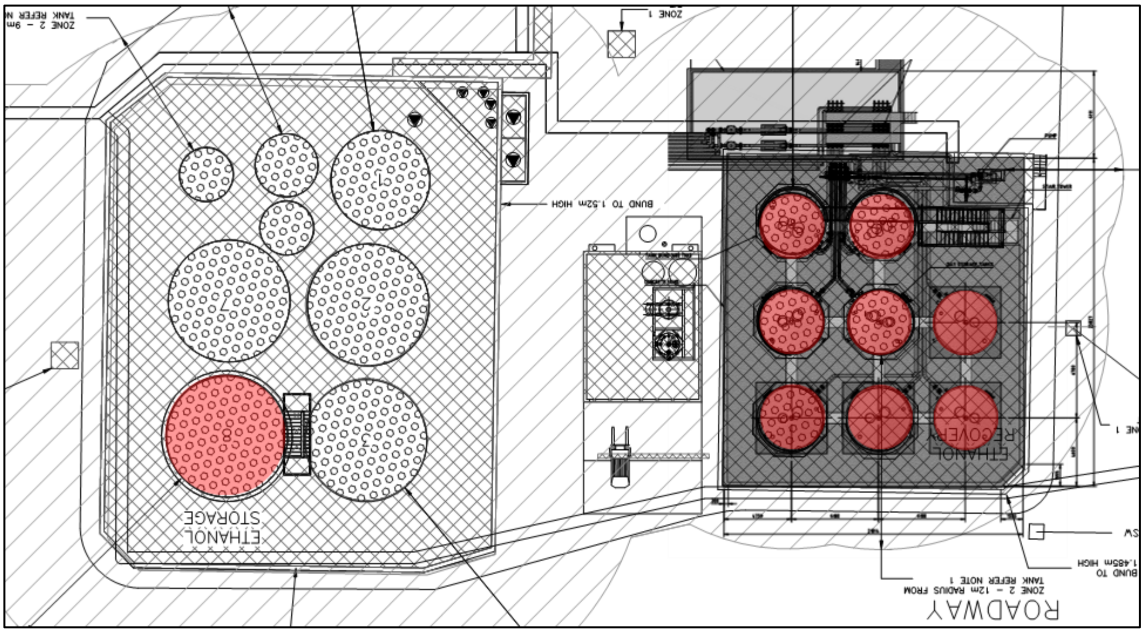

Figure 6: Complete Tank Arrangement After Expansion.

Each tank will contain a solution with 96% Beverage Grade Ethanol, the balance being water. The Day Tanks will be filled with "fresh" Ethanol from the production plant, then the Ethanol will be transferred from each Day tank to the Storage Tank. Each tank will have pressure relief vents on their roof. The existing tanks are currently venting directly to atmosphere from the pressure relief vent, while being filled.

For the future operation, the following contemporary filling/transferring operations are considered:

- 2 x Day Tanks filled at the same time, with filling rate 10 m³/h
- 1 x Transfer from Day tank to Storage Tank, with transfer rate 150 m³/h

The gas mixture present in the tank's head space, to be considered as the vent output to be treated by the scrubber, will be Ethanol + Nitrogen. The maximum concentration of Ethanol in the vented gas is expected to be 17%, with a maximum temperature of 40 °C inside the tanks. Based on the above, the following design conditions were applied for sizing the proposed system (Table 3):

Table 3: Parameters Used in Sizing Proposed System.

Parameter	Peak Load	Average Load
Vented Gas Flow Rate, Nm^3 (wet)/h	145	145
Vented Gas Flow Rate, Am^3 (wet)/h	170	170
Vented Gas Temperature, °C	40	25
Vented Gas Pressure (in the tank), kPa	2	2
Nitrogen %	83	93
Ethanol %	17	7

5.2 Vapour Recovery Unit (VRU)

The design criteria for the Vapour Recovery Unit (VRU) will achieve the following outputs:

- < 20 mg/Nm^3 Ethanol Concentration at the stack.
- 0.7 - 1 m^3/h of recoverable effluent, which is going to be water with maximum 7.8% w/w Ethanol concentration.

When there will be no tanks being filled or transfer operations underway, the scrubber will run, discharging simple chilled water as effluent. When the concentration of the ethanol in the vented gas is lower than 17%, the concentration of the ethanol in the scrubber's effluent will be lower than 7.8%.

The system will be connected to all the nine tanks (8-day tanks + 1 storage tank) and will extract nitrogen from the day tanks only when they are being filled, or from the storage tank when it receives ethanol from the day tanks. This will consider a maximum requirement of 2 x day tanks being filled + 1 x transfer to the storage tank at the same time.

When any of the tanks are idle, the connection to the scrubber will be shut off by means of a butterfly damper. If the tank is being filled, the damper will be opened so that no pressure will build up in the tank headspace and the gas will be free to flow to the scrubber. Since the gas mixture will be Nitrogen + Ethanol, anti-explosion provisions in the ducted line to the scrubber will be installed.

A vertical, counter-current Packed Bed Tower (PBT), Figure 7 below, is employed to remove the ethanol from the associated vented gas. Chilled potable water is delivered to a spray nozzle at the top of the packing to distribute the scrubbing liquid evenly across the top of the packed bed. The scrubbing liquid trickles down through the packed bed, whilst the vented gas is fed into the base of the vessel, and thus travels up through the packed bed (see Figure 7 & Figure 8) in a counter-current fashion. The packed bed consists of high-performance packing pieces that ensure intimate contact of the liquid with the ethanol in the gas, promoting the absorption of ethanol from the gas phase into the scrubbing liquid.

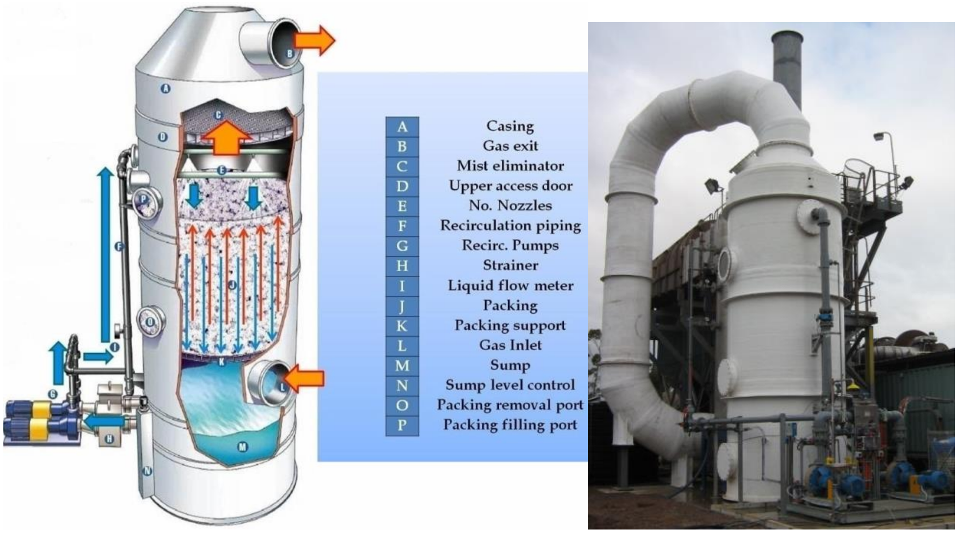

Figure 7: PBT Schematic Diagram (left), Example Photo of Installed Unit (right).

The scrubber will work in a once through fashion, with the scrubbing solution continuously being discharged to recovery. For this application, the scrubbing media will be water only. The scrubbed process gas passes through a mist eliminator, which consists of a second layer of special packing material. This captures any scrubbing liquid droplets that are swept into the exiting gas stream. The de-entrained process gas is then discharged from the top of the PBT. An example of the inner workings of the unit is displayed in Figure 8.

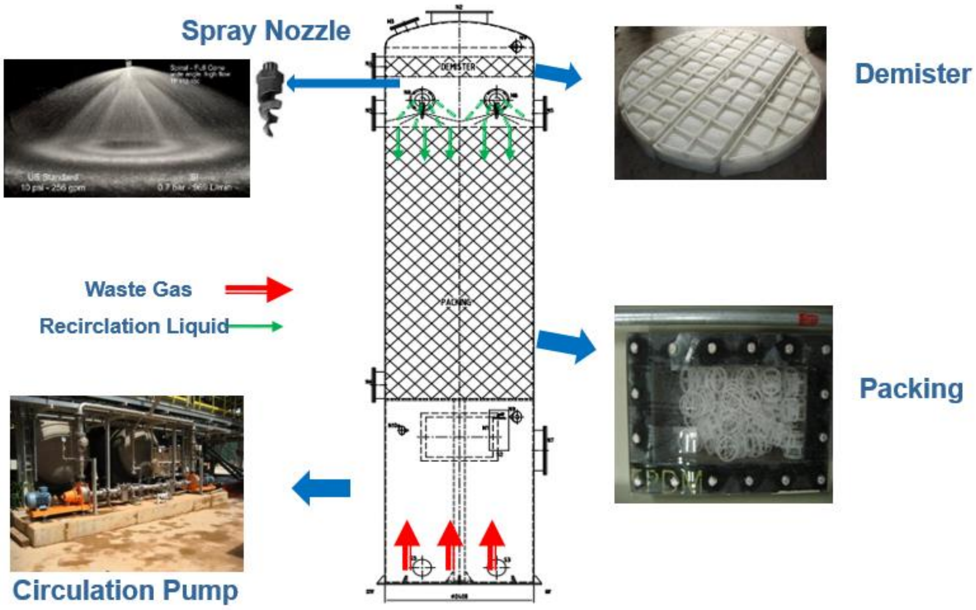

Figure 8: PBT Flow Diagram & Components.

The proposed new Induced Draft (ID) Fan will be Induced Draft SWSI type, complete with expansion joints on inlet and outlet. Figure 6 below illustrates the proposed site-specific unit for Bomaderry. Figure 7 presents two options for connection to the tank arrangement, depending on Shoalhaven Starches preference. Further discussion is required between TAPC, M. E. Engineering and Shoalhaven Starches.

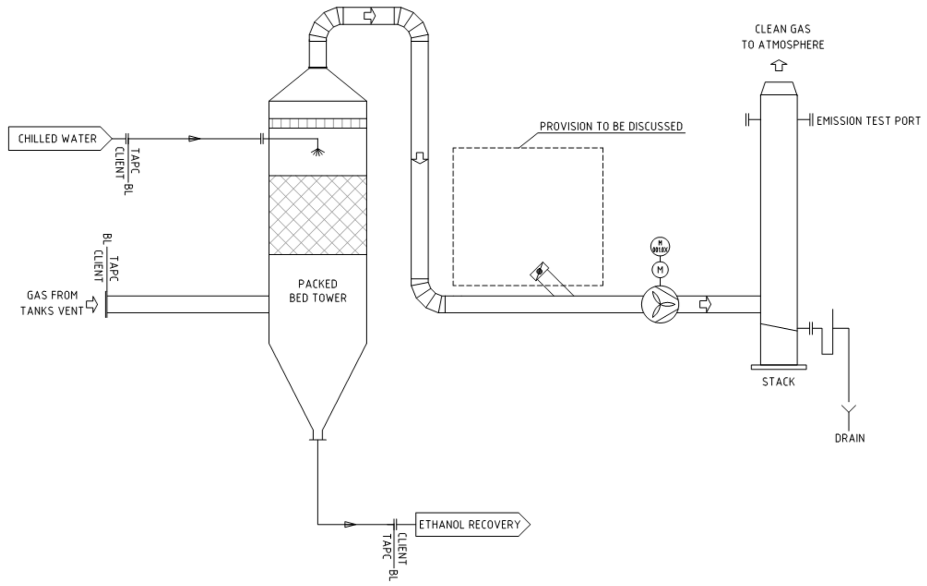

Figure 9: Preliminary PFD – TAPC, 24/06/2021.

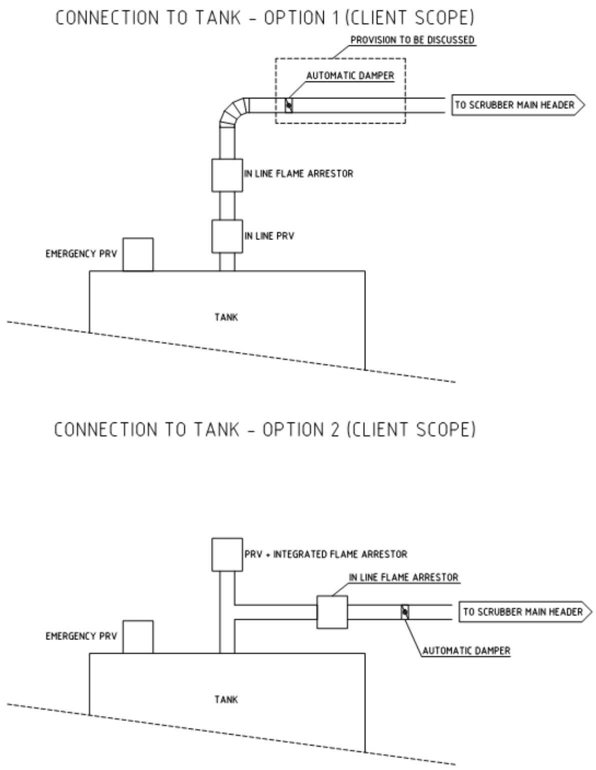

Figure 10: Preliminary PFD Tank Arrangements – TAPC, 24/06/2021.

Packed bed towers (PBT) are one of the most widely utilised mitigation measures in this type of industry, due to the unit's reliability and relative low cost, second to a thermal oxidiser. For VOC removal, packed-tower absorbers can achieve efficiencies greater than 99 percent for some pollutant-solvent systems, although typically this range is from 70 to >99 %. The capital cost of setting up the proposed PBT is between \$150,000 to \$400,000 per sm^3 /sec, with an annualised cost of \$36,000 to \$165,000 USD per m^3 /sec (US EPA Air Pollution Control Technology Fact Sheet, n.d.).

Advantages of a PBT best practice option include a relatively low pressure drop, low corrosivity, capability of relatively high mass-transfer efficiencies, customisable height and/or type of packing to improve mass transfer without purchasing new equipment, relatively low capital cost, small space requirements and an ability to collect particulate matters as well as gases.

Disadvantages include the chance that the system may create a water or liquid disposal problem in terms of waste disposal, the waste product that is collected is in liquid form which can be difficult to contain and dispose of properly, particulate matter may cause plugging of the bed or places, if fiberglass-reinforced plastic construction is used the unit may be sensitive to temperature, and maintenance costs are relatively high (US EPA Air Pollution Control Technology Fact Sheet, n.d.).

Considering a 70 – 99 % emission reduction of 2020's yearly ethanol emission rate of 22,867 kg from this tank arrangement, it is expected that the proposed packed bell tower scrubber will reduce these emissions to between 229 kg – 6860 kg per year.

Applying a liberally estimated 0.05 m^3 constant loss of volume of ethanol from the tank arrangement in place, derived from previous work carried out by Assured Environmental on similar tank valve release systems, the low-end 70 % reduction of total ethanol per year (6860 kg) would equate to 39.2 mg/m^3/hour. By comparison, the higher-end reduction of 99 % of yearly ethanol (229 kg) equates to 1.3 mg/m^3/hour, displayed below in Table 4. Considering this range of reduction in emissions, and the claimed emission output of <20 mg/Nm^3 Ethanol Concentration at the stack as stated earlier, it should not be difficult to maintain an emission level of 40 mg/m^3/h as per current guidelines and license limits for VOCs once the tank arrangement is upgraded and the PBT is installed and functioning efficiently.

5.3 Emissions Monitoring Limits/Guides

Air monitoring frequency and limits for the proposed infrastructure are taken from the Bomaderry site NSW EPA licence – NSW EPA Environment Protection Licence No. 883, for similar air emissions infrastructure. Additional guidelines are taken from EPA consultation, presented in Excerpt 2 under the classification of a packed bell tower as a vapour recovery unit. Sampling of storage tanks is not a regular occurrence, although if a complaint is made regarding ethanol emissions the below information aims to provide a guide. Pollutants to be tested would include (at a minimum) volatile organic compounds as n-propane equivalent, with a limit of 40 milligrams per cubic metre (assumed best practice). Table 4below illustrates guidelines and existing VOC licence limit values from NSW EPA.

Table 4: Ethanol (VOC) Operational Guidelines.

Limit or Guideline	Amount
EPA VOC limit from licence, mg/m^3/hr	40
EPA VOC guideline from excerpt 2 (VRU), mg/L in 4 hours	10
EPA VOC guideline from excerpt 2 (VDU), mg/m^3	<40

Table 5: Ethanol (VOC) Projected Performance from Proposed PBT.

Source	Amount
Proposed unit specifications (from manufacturer), mg/Nm^3	<20
Theoretical range calculated from existing site data, mg/m^3/hour	1.3 – 39.2

6 MANAGEMENT PLAN

6.1 Monitoring of Emissions

Operator inspections are carried out on a daily basis using an Inspection Checklist. The Checklist will include items that may affect ethanol emissions and must be updated for the following items:

- Emergency vents on ethanol storage tanks are operating effectively;
- Flame arresters and anti-explosion systems operational;
- Scrubber is operational;
- No odours detected;
- Continuous PLC SCADA monitoring of the VRU key process parameters.

6.2 Performance Indicators

Ethanol presence can be determined by way of human olfactory response. Relying on this form of assessment may lead to an unnecessary health risk. In this case it would be advantageous to determine the presence of ethanol by using a VOC analyser such as a photo-ionisation detector (PID). Provided the PID is well maintained and calibrated as per the manufacturer's instructions a quantitative assessment of VOC emissions could be determined to assess the scrubber performance.

The generation of ethanol emissions are dependent on the optimum operation of the scrubber. If the scrubber is not operating efficiently, unnecessary emissions will be released. The performance indicators will be on-site odour identification by personnel, annual VOC site mass balance calculations and effective operation of pipelines (regular scheduled maintenance, frequent inspections for leaks by operators).

The Environmental Protection Licence for the facility 883 does not include requirements for ethanol monitoring of the storage/day tanks. If odour complaints occur, consideration of carrying out VOC monitoring of the scrubber is recommended.

6.3 Responsibilities

The following outlines the responsibilities of Shoalhaven Starches (Ethanol) personnel in relation to ethanol emissions.

- Site Manager:
    - Responsible for ensuring that the Ethanol Plant Manager is aware of, and able to fulfil their obligations to implement this VOC-MP at site level.
- Ethanol Plant Manager:
    - Responsible for ensuring that this plan is consulted and complied with, ensuring that worker training, reporting, and investigating of incidents is carried out.
    - The Ethanol Plant Manager shall ensure that this VOC-MP is maintained, and if updated, that the plan is approved by relevant senior management and verified through the controlled document process.
    - Work with HSE personnel to ensure that corrective actions are taken.

- HSE Personnel:
  - Responsible for the investigation of odour/VOC emission complaints and incidents to identify likely unforeseen ethanol releases and reporting to the Plant Manager.
  - Work with the Ethanol Plant Manager to ensure corrective actions are taken.
- Maintenance Manager:
  - Responsible for ensuring that preventative and unforeseen maintenance activities are carried out on VOC control devices and systems correctly.
- All workers:
  - Responsible to ensure they follow this Management Plan and fulfil the requirements set within.
  - Required to report any operations / equipment or behaviours which may lead to increased VOC emissions from the site.

6.4 Actions for Implementation

The following actions are proposed to be included in daily checks:

- A daily checklist for personnel to use when inspecting the tanks prior to each shift. This checklist should be based on the equipment maintenance and identify any engineering or operational concerns that may impact VOC emissions (such as faulty seals, escaped product).

6.5 Complaints Procedure

Third party environmental complaints are managed in accordance with site policy. Specifically, the Environmental Advisor or their delegate will:

- record complaints as an incident in site HSE management program;
- investigate and verify complaints and assess if excessive off-site impacts have occurred;
- implement corrective measures including modification of methods and operational techniques to avoid recurrence / minimise ongoing adverse impacts;
- complete monitoring / additional investigations to verify the adequacy of the recommendations, as required;
- notify the complainant of actions taken; and
- continue to monitor activity, if required.

6.6 Training and Awareness

Employee training and induction of staff plays a critical role in supporting the safe and environmentally responsible conduct of operations. All personnel have environmental management responsibilities. These responsibilities should be communicated to all personnel via appropriate environmental management training, including initial environment induction.

Environmental awareness training is provided to all personnel involved with the site, including all subcontractors and visitors, via inductions, as per site specific training & competency management standards.

This method of environmental awareness training ensures that all personnel are aware of:

- the importance of conformance with environmental policy and procedures and the requirements of the environmental management plan and associated sub-plans (if applicable);

- the significant environmental aspects of the operational sites, and the environmental benefits of improved work performance;

- their roles and environmental responsibilities for achieving conformance with environmental policy and procedures and with the EMP, including site emergency preparedness and response requirements; and

- the potential consequences of departure from specified operating procedures.

A site's environmental induction is usually valid for a period of 12 months, after such time the person will undertake refresher training. All personnel, including subcontractors, attend inductions prior to commencing work on the site. Records of inductions are recorded in the site training matrix.

6.7 Review of this Management Plan

The Plant Manager (or HSE) must ensure this Management Plan is reviewed (and revised) at least once every two (2) years or whenever:

- there is a significant change in the environment or operations
- there is a significant incident / breach
- there is a change in applicable legal and other requirements; and/or
- as otherwise requested.

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APPENDIX A: BEST PRACTICE LITERATURE REVIEW

Introduction

The following information reviews all feasible and reasonable mitigation measures available for this type of tank arrangement and industry, to ensure best practice is clearly identified. It is worth noting before consideration of all available abatement measures, that floating roof tanks were initially considered as the mitigation measure for this expansion project as a recommendation by NSW EPA. Due to the high potential of contamination issues with Shoalhaven Starches (Ethanol) final product, this type of mitigation measure has been agreed upon by NSW EPA and Shoalhaven Starches as not suitable.

There are many physical, chemical, and biological treatments available to remove VOCs from air by either recovery or destruction (Berenjian et al., 2012). Treatment systems can involve either a single phase or multi-phase hybrid arrangement, depending on the budget and removal/treatment required. Of the single-phase VOC abatement methods available for this industry, the options available can be categorised as either capture methods or destruction methods.

Capture methods involve absorption, adsorption, condensation, membrane separation or biofiltration. Destruction methods include thermal oxidation, catalytic oxidation, thermo catalytic oxidation, photocatalytic degradation, or plasma catalysis. Hybrid (multi-phase) methods can involve dual functional materials or a combination of methods (Krishnamurthy et al., 2020).

Adsorption

Adsorption can be a useful VOC abatement method, retaining gas molecules on a solid surface that possesses a high surface area per unit mass, usually comprised of granular activated carbon, zeolite, macro-porous polymers, silica gel or sodium-aluminium silicates. This operation usually employs the method of fixed-bed adsorption – the most commonly used in industry.

Fluidised-bed adsorption utilises the velocity of the waste gas stream to maintain the adsorbent in a fluidised state. The adsorbent is regenerated in a heat exchanger, positioned underneath the adsorber, and subsequently returned pneumatically to the fluidised bed as a continuous process. Continuous moving-bed adsorption involves the adsorbent entering via the top of the adsorber, which is continuously fed counter-current to the waste gas stream. The saturated adsorbent exits the bottom of the vessel and is continuously transferred to a moving-bed regenerator.

Pressure-swing adsorption is characterised by four distinct steps: pressure built up by the gas entering the adsorber, adsorption occurring once the target pressure has been attained, once the bed is saturated the adsorption chamber is de-pressurised and finally the adsorption chamber is purged at either low pressure or under vacuum. This four-step process causes a separation of components according to their bond strength to the adsorbent.

Vacuum regeneration allows the desorption process to occur at ambient adsorbent temperature, and this is preferred for recovering temperature-sensitive VOCs. As an added bonus, this method can be used to regenerate granular activated carbon, zeolite, and polymer adsorbents.

- Pros: adsorbers can handle a wide range of VOC concentrations in waste gas streams and can cope with fluctuations in VOC concentration and waste gas flow rate.

- Cons: they are not recommended for high humidity or particulate matter containing streams as efficiency will be greatly reduced (Muzenda, 2013).

Absorption

Absorption is also known as wet scrubbing, is a diffusion-controlled, mass transfer process between a soluble gas and a solvent. During absorption, the waste gas stream pollutants are effectively removed by contacting the gas stream with suitable scrubbing liquor in an absorption tower, such as the proposed packed bell tower.

- Chemical absorption is utilised exclusively to absorb acid gasses through a chemical reaction of these gases with the scrubbing solvent.

- Physical absorption processes are multi-use, and can absorb acid gas components, as well as hydrocarbons and other pollutant compounds.

- Fibrous packing scrubbers contain mats of fibrous packing material made from glass, plastic or steel. Pre-cooling of the waste gas stream before it enters the scrubber assists in condensing some of the volatile pollutants, thereby optimising the absorption process.

Blockage of nozzles and plugging of the fibrous mats can plague the efficient operation of this method. Moving-bed scrubbers consist of zones of mobile packing in the form of low-density plastic spheres, which are held in place by support grids. A mist eliminator is installed inside these scrubbers, and the spherical plastic balls are kept in a constant state of agitation and fluidisation to help prevent plugging and clogging of the packing and scale build-up. This method is typically used for removal of sulphur dioxide, hydrogen fluoride, odours, and dust from waste gas streams and where scaling is a challenge. Impingement plate scrubbers consist of several bubble-cap or sieve trays stacked in a vertical tower. Baffles are situated at a short distance above the plate apertures. The scrubbing liquid flows down the tower while the waste gas stream flows upward. Contact between the liquid and the VOC-laden gas occur on the plates with openings that allow the gas to pass through. As the gas bubbles through the liquid layer, the froth generated creates the contact point between the absorbent and the soluble VOC, where mass transfer occurs.

Plate scrubbers are highly efficient and are easier to maintain compared to packed columns. Plate towers exhibit larger pressure drops than packed scrubbers. A further drawback of plate scrubbers is the large liquid hold-ups at high gas flow rates. They are commonly used in the absorption of acids, sulphur dioxide and odours – not suitable for foaming liquids and less cost-effective than packed towers in terms of VOC abatement. Pros: scrubbers can handle a wide variety of waste gas flow rates and high humidity (>50 % relative humidity) air streams. They are relatively simple to maintain and are able to process flammable and explosive gases with low risk – important for this proposal considering storage of ethanol. Cons: They are usually susceptible to particulate matter plugging. Entrainment of the liquid absorbent in the exit gas stream could pose new pollution challenges (Muzenda, 2013). Only absorbent soluble VOCs are recovered, other treatment options may be required for those which are insoluble, which is not a concern for this project as ethanol is easily soluble in water.

Condensation

Condensation, refrigeration, and cryogenic systems are used on gas streams that contain only volatile organic compounds. A Strength of these methods is the ability to handle both intermittent waste gas feed and continuous flow rates. They can be used for recovering both non-halogenated and halogenated VOCs from waste gas streams without the need for expensive auxiliary equipment, and they are ideal for high boiling point VOCs. A weakness of these mitigation measures is that the freezing of water vapour and VOCs in condenser tubes reduces the heat transfer efficiency and hence recovery efficiencies. The condensation process can also generate a wastewater stream that can be challenging to dispose of (Muzenda, 2013). An Electrostatic Precipitator or Wet Electrostatic Precipitator is slightly different to the pre-mentioned measures, as they use electrostatic forces to target and remove specific particulates. This presents an advantage over scrubbers or baghouses of relatively lower energy costs due to their reduced operating field, although this technology is usually suited to filtering of particulate matter and liquid/gas streams, with incidental control of VOCs (US EPA Air Pollution Control Technology Fact Sheet, n.d.).

Recovery Scrubbers

Ethanol plants generally employ adsorption/absorption recovery scrubbers (proposed) or destructive regenerative thermal oxidisers as best practice, but there are growing progressive technologies such as biotrickling filters, which could soon replace these methods due to their environmentally friendly and low economic cost (Duerschner, 2019).

One study illustrated an ethanol elimination capacity (while using a biotrickling filter) of greater than 220 g/m^3 over a bed contact time of 57 seconds (Cox et al., 2001). Another study presented findings that biotrickling filters remove methanol of over 100 g/m^3/h at low temperatures – up to 70 °C (Kong et al., 2001) A further study claimed 100 % removal of pollutants at 320 g/m^3/h for a single pollutant stream such as ethanol (Balasubramanian et al., 2012), showing promise that this method could be employed as either a standalone mitigation measure or as part of a hybrid combination in the future.

At a cost of $8.7 - $14/1000 m^3 $_{air}$ in the case of non-chlorinated volatile organic compounds (Deshusses et al., 2000) this method is considered relatively cheap, compared to a packed bed tower or thermal oxidiser. More research and testing are required before this method can confidently be recommended and utilised broadly throughout industry.

Membrane

Membrane processes available for treating VOCs in vapour removal include vapour permeation, gas/vapour separation, pervaporation, membrane contactors and membrane bioreactors.

Of these, the vapour permeation method is applied in industry and is regarded as the most up-to-date, technically feasible membrane process available (Zhang et al., 2002). It is rapidly growing by the aid of previous experience with reverse osmosis and pervaporation technologies, achieving anywhere between 70 – 98.5 % removal of VOCs, depending on the permeability of the membranes and pressures between them.

Vapour permeation is primarily used to economically recover organic solvents from exhaust streams, whereas the membrane contactor method is usually used for removing or recovering VOCs from air or wastewater. Membrane contactor VOC removal involves feeding gas mixture to the lumen of hollow fiber membranes for a short period of time. Following this, the feed flow is stopped for a brief period, after which the feed gas flow is captured, then the fiber lumen is resumed and a vacuum is maintained continuously on the shell side. The purification capacity of the process has been shown to be considerably higher than that of the conventional steady-state operation of the membranes.

The membranes show high selectivity of organic vapours over nitrogen – an advantage for site at Shoalhaven Starches (Ethanol) which plans to blanket ethanol vapours with nitrogen. The membrane separation techniques above are recognised as effective, energy-saving, and economical methods for removing VOCs, although they are usually suited for mass transfer in liquid/liquid or gas/liquid systems.

- Positives of this treatment method include the fact that membranes can handle most volatile organic compounds, and the VOCs recovered are usually recycled and hence no waste is generated. Simplicity is the other attractive strength of these methods.

- Some weaknesses of this method: the increase in vapour concentration above the Lower Explosive Limit (LEL) of 3.3 % for ethanol (Wermac.org, 2008) during VOC permeation can result in the accumulation of an explosive mixture.

Overall, they are usually not capable of treating waste gas streams to acceptable disposal limits and hence additional treatment is required (Muzenda, 2013) making this method unsuitable for Shoalhaven Starches (Ethanol).

Thermal oxidisers

Thermal oxidisers are an accepted air pollution control technologies, and widely studied for over twenty-years (Krishnamurthy et al., 2020), employs a method of heating the pollutant in a combustion engine, essentially breaking down the pollutant (in this case ethanol) into water vapour and carbon dioxide. Modern systems can treat VOC concentration ranges from 100 to 2000 ppm at a destruction and removal efficiency rate of 95-99% (Choi, 2000). While simple and reliable, this method can be quite energy-dependent, suffering from extremely high energy penalties that make it widely inefficient for large-scale industrial deployment.

The capital cost involved with setting up and running a regenerative/recuperative thermal oxidiser has been reported at around $850,000 - $1,000,000 AUD ($483,000 capital, $432,000 annual cost – (van der Vaart et al., 1991), adding to its less desirable viewpoint financially. Having said that, thermal energy recovery rates can be as high as 70 percent (Baynham, Randall et al., 2017) (Krishnamurthy et al., 2020), employing a system of energy capture and re-use by using exit gas to preheat the incoming feed stream, combusting air, or both via a heat exchanger. This primary thermal energy recovery system is usually included in the price of the initial unit, but significant investment can be made (if desired) to achieve up to 95 % recovery (Choi, 2000).

If there is specific on-site use for a secondary energy recovery system that makes use of recovered steam or hot water, a thermal oxidiser could seem attractive for implementation, but the installation of this system will involve further up-front capital investment.

Thermal catalytic oxidation

Thermal catalytic oxidation, a specialised version of a thermal oxidiser, has shown great promise for the mitigation of a wide variety of VOC types at dilute concentrations (>1 %) in flue gas streams, and has been incorporated into many industrial streams.

An advantage of this method is a reduced operating cost ($341,000 annual) compared to a traditional thermal oxidiser (432,000 annual) (van der Vaart et al., 1991) by a reduction in fuel required. Fouling of the catalyst is possible, leading to a potential release of heavy metals, phosphorous, sulphur and most halogens (Yatavuk, 2000) (Krishnamurthy et al., 2020).

If used correctly, operational temperature is half of thermal oxidisers (500 °C compared to around 1000 °C), leading to the formation of less dioxins and noxious products (Kamal et al., 2016). By using the correct catalyst, concentrations of up to 1600 ppm can be 100% removed at only 200 °C (Yang et al., 2019). In general, a trade-off exists between the higher capital costs of thermal catalytic incinerators ($889,000 vs $483,000) and the higher annual operating costs of thermal oxidisers ($432,000 vs $341,000) (van der Vaart et al., 1991).

Photocatalytic degradation

Photocatalytic degradation has come to the forefront of VOC mitigation in recent years as a potential alternative to thermal catalytic oxidation, due to high VOC degradation rates in extremely dilute concentrations (ppb range).

Indoor air VOC abatement would therefore be well suited to this method; however, photocatalytic irradiation has been shown to have potential to formulate many harmful by-products. In an industrial setting, this method boasts many advantages such as high chemical stability, high oxidising capability, and non-toxicity and low cost while using titanium oxide as the semi-conductor.

Photocatalytic conversion of VOCs can be in the range of 30-100%, depending on several factors, such as type of support materials, type of VOCs, VOC concentration and composition, the oxidation/reaction pathways, residence time, relative humidity, and light intensity (Das et al., 2019). Cost of a photocatalytic unit for indoor use has been reported as $16,310 per m^3, with an annual cost of $11,800 per m^3 p.a. (Henschel, 1998). This method has only been studied at the laboratory scale up until recently and is therefore not well-enough developed as a trustworthy industrial implementation strategy (Krishnamurthy et al., 2020).

Plasma catalysis

Similarly to photocatalytic degradation, a relatively new technology for VOC oxidation, plasma catalysis, were up until now confined to the laboratory. Unlike thermal or catalytic oxidation, the plasma process operates at low temperatures, as the reaction rate is primarily determined by energy input rather than the reaction temperature.

The mechanisms of plasma-assisted catalysts are not completely clear, because of the complicated influence factors. Herein future study is needed (Wang et al., 2018). The lower operating costs compared to both thermal oxidation and catalytic thermal oxidation is a considerable financial benefit, although plasma species decompose VOCs at random and the selectivity toward the desired product is not yet satisfactory.

Experimental results are promising, with removal efficiency of common VOCs generally around the 95 % mark at concentrations between ppb to 500 ppm (Trinh et al., 2016). It is hoped plasma catalysis can be considered in the very near future as an appropriate large industry-scale mitigation measure for VOC removal.

Hybrid Systems

While each system involving capture or destruction of VOCs has its own advantages and disadvantages, the synergistic effect (or hybridisation) of multiple systems can play an important role in minimising emissions and costs. For example, hybridisation of membrane separation/condensation and membrane separation/combustion for removal of VOCs from air in workshops have proven economical and efficient (Buzek et al., 1999).

Integration of adsorption and photocatalysis degradation is a promising technological development for VOC removal, due to its environmentally friendly status with low energy consumption, renewability, and its effectiveness (Zou et al., 2019). This area requires further study before implementation in large-scale industry, especially focusing on ethanol removal/treatment (Krishnamurthy et al., 2020) as hybridising a mitigation measure generally tends to increase complexity and initial capital investment.

Table 6: Benchmarked VOC Mitigation Measures.

Method	Initial Capital Cost $	Ongoing Annual Cost $	VOC Removal Efficiency %
1. Packed Bed Tower (proposed)	150,000-400,000	36,000-165,000	70-99
2. Thermal oxidiser	483,000	432,000	95-99
3. Thermal Catalytic Oxidiser	889,000	341,000	100
4. Photocatalytic Degradation	16,310/m^3	11,800/m^3	30-100

Summary

From the discussion and the summarised Table 5 above, the Packed Bed Tower unit proposed by TAPC is considered the primary option for this site as a practical, reasonable solution to mitigate VOC emissions from the current and/or expanded ethanol tank arrangement.

This conclusion is based on the relatively reasonable price, and a reduction in ethanol/VOC emissions that will range between 70-99 %. Considering the current EPA licence limit of <40 mg/m^3 VOC as n-propane equivalent for other compliance sampling locations as listed in the Bomaderry site licence, No. 883, and the EPA guideline of 10 mg/L as n-propane in a 4-hour block for a vapour recovery unit (excerpt 2), this unit will be able to mitigate current and future projected ethanol emissions. If this, for some unforeseen reason, cannot be achieved and these limits are exceeded within the first year of operation, a thermal oxidiser should then be considered as the next best option.

APPENDIX B: TANK DESIGNS