GAS IMPORT JETTY AND PIPELINE PROJECT
ENVIRONMENT EFFECTS STATEMENT
INQUIRY AND ADVISORY COMMITTEE

TECHNICAL NOTE

TECHNICAL NOTE NUMBER:	TN 42
DATE:	26 October 2020
LOCATION:	Crib Point Jetty Works
EES/MAP BOOK REFERENCE:	Technical Report G - section 4.1.1, 4.5.1, 4.4.6, 8, table 6.1, figure 4-3, figures 7-10 to 7-18 and Appendix B Chapter 4 - Figure 4-3 Chapter 12 – Table 12-3 Technical Report K – Appendix E Attachment VIII - Appendix F and G, Table 21
SUBJECT:	Response to RFI numbers 64 to 74 in relation to air quality
SUMMARY	Responses relate to subsections: Sensitive uses, Receptor grid spacing, Formaldehyde, Discharge points and Air emissions.
REQUEST:	This technical note has been prepared in response to the Request for Further Information 64- 74 provided to the proponents by the Crib Point Inquiry and Advisory Committee dated 16 September 2020.

NOTE:

[64] Explain if the findings on impacts on sensitive receptors would alter with the inclusion of the Victorian Maritime Centre.

1. Figures 7-10 to 7-20 show that the Victorian Maritime Centre is not impacted by the lowest graphed isopleth concentrations for any pollutant. Therefore, there would be no change to the *Technical Report G: Air Quality impact assessment* conclusions if the Victorian Maritime Centre was included as a sensitive receptor.

[65] Justify the selection of the grid spacing used, given that a receptor grid spacing of 100 metres was used in the 4 by 4 kilometre Cartesian grid, but advice from EPA recommends a 50 metre spacing.

2. '*Guidance notes for using the regulatory air pollution model AERMOD in Victoria, Publication 1551 (October 2013)*' as referenced in the Air Quality Tech report (EPA 2013c) recommends a 50m spacing. However a grid spacing of 100m resolution was considered an appropriate resolution so that the maximum concentration is not significantly underestimated. A 100m spacing is consistent with the most recent *EPA Guidance Notes For Using AERMOD Publication 1551 Revision 4 November 2014* which recommends a minimum of 100m spacing. Publication 1551 is enclosed with this Technical Note. Grid

spacings of 50m or 100m resolution has no impact on results at sensitive receptors locations and will not alter the report conclusions.

[66] Provide advice on the potential significance and impacts with a +/-20% change in formaldehyde emissions from the 'Wartsila' engines operating with gas as the primary fuel and potential frequency and severity of potential human exposure.

Air emissions

3. As stated in Section 4.4.4 – "Emission factor tolerances are provided in the specifications, and are as high as ±32% (for VOCs), however it is likely that any emission rate fluctuations due to these tolerances are expected to cancel out with four units operating concurrently. Based on this, emission rates for the Wärtsilä 50DF were calculated based on the listed emission factors without consideration for the tolerances."

4. The dispersion modelling has used a conservative approach based on worst case operational scenarios. Contrary to the basis upon which the modelling was undertaken, the FSRU is expected to only ever operate at peak capacity in short durations for approximately 10 per cent of the year. Frequency of occurrence results indicate that if the FSRU operated *continuously* at peak capacity *for the entirety of the year*, formaldehyde concentrations would be below the criterion for at least 99 per cent of the time at locations greater than 60 metres from the FSRU.

5. Modelling undertaken in respect of a more realistic but still conservative operating scenario (wherein the FSRU is assumed to operate at 500mmscf/d throughout the *entirety of the year*) predicts that formaldehyde concentrations will be below the criteria at locations greater than 150m from the FSRU 100 per cent of the time.

Human health risk assessment

6. Paragraphs 42 to 47 of Dr Roger Drew's evidence describes his independent assessment of the human health implications of formaldehyde concentrations arising from the Project. Based on conservative operating scenarios, and having regard to maximum predicted ground level concentrations, Dr Drew concluded that formaldehyde concentrations are between 1.5-10 times lower than the relevant health assessment criterion. Dr Drew concludes that, based on the worst case assumptions embedded in the dispersion modelling and the very low frequency of the maximum predicted exposures, persons who may be exposed to these modelled concentrations will not experience adverse health effects.

7. Based on the table in paragraph 47 of Dr Drew's evidence, even if there was a 20% increase in formaldehyde concentrations attributable to the Wartsila engines, formaldehyde concentrations would still comfortably comply with the relevant health assessment criterion.

8. This notwithstanding, as stated by Dr Drew in paragraph 8 of his witness statement, *Technical Report G: Air Quality impact assessment* is based on a number of conservative assumptions which likely contribute to an overestimation of the maximum predicted ground level concentrations.

[67] Explain how a +20% increase in formaldehyde emissions will compare with SEPP (Air Quality Management) design criteria, and what is the likely extent of the plume, including frequency and severity of potential human exposure.

Assessment against SEPP AQM criteria

9. Modelled scenarios presented in *Technical Report G: Air Quality impact assessment* are based on very conservative assumptions and show that maximum Formaldehyde concentrations at sensitive receptors are 43% of the criteria (Table 7-9). If there was a 20% increase in formaldehyde concentrations, then the formaldehyde concentrations would still comply with the relevant health assessment criterion.

10. Furthermore, as stated in Section 4.4.4 – "*Emission factor tolerances are provided in the specifications, and are as high as ±32% (for VOCs), however it is likely that any emission rate fluctuations due to these tolerances are expected to cancel out with four units operating concurrently. Based on this, emission rates for the Wärtsilä 50DF were calculated based on the listed emission factors without consideration for the tolerances*."

Human health risk assessment

11. As stated above, Dr Drew concluded that formaldehyde concentrations are between 1.5-10 times lower than the relevant health assessment criterion (see paragraph 45 and 47 of Dr Drew's evidence) and therefore persons who may be exposed to these modelled concentrations will not experience adverse health effects.

12. In addition, implementation of MM-AQ11 will enable quantification of FSRU emission rates to ensure they comply with design specifications and impact assessment assumptions

[68] Clarify model inputs of obstacles within the immediate vicinity of the discharge points (funnels) that could cause plume downwash.

13. Figure 4-1 shows the building as entered into AERMOD. Obstacles within the immediate vicinity of the discharge points (funnels) that could cause plume downwash are the main funnel and the bridge. These obstacles were taken into account in the modelling.

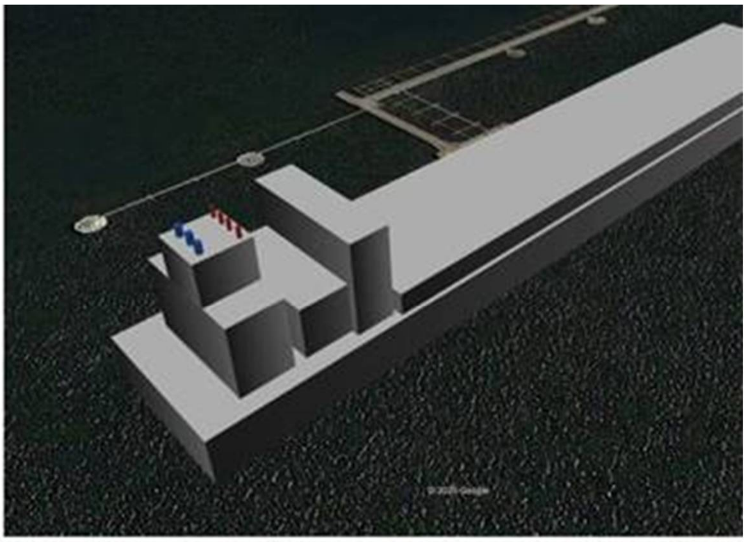

Figure 4-1 FSRU orientation and location of boilers (blue) and engines (red) discharge points

[69] Provide an assessment of the feasibility of enhancing plume dispersion for emissions from the boilers and generator engines on the FSRU.

14. It is possible to modify the exhaust stacks to a vertical position or extend them higher, both of which would be expected to have the effect of enhancing plume dispersion.

15. However, there are practical challenges associated with making these modifications. For example:

(a) The vessel is permitted to trade as an LNG carrier, it is unclear what impact this would have on vessel drag and emissions dispersion while the vessel is under sail; and

(b) Additional rain collectors may need to be installed in the exhaust stacks to account for the extra rain collection if they were to be installed in a vertical position

16. Therefore, it is unlikely that the modifications would be considered feasible.

17. In addition, the proponents note that, it is not expected that changes to the exhaust stack parameters would alter the conclusion of the air modelling assessment presented in EES Technical Report G which provides that '*The air modelling assessment and HHRA demonstrates that there is a low risk of air quality impacts from the FSRU operations and emissions are unlikely to have regionally or State significant effects on the air environment. An air quality monitoring programme should be designed and implemented to confirm FSRU emission rates comply with design specifications (MM-AQ11)*'.

[70] Provide information about best practice measures to prevent fugitive or emergency venting from tanks including from rollovers on the FSRU, benchmarked for both FSRU and equivalent land based facilities with justification for chosen benchmarks.

18. Emergency venting from the FSRU LNG tanks would be required to prevent pressure build up and overpressure of the cargo tanks. The FSRU has multiple ways to manage tank pressures, the following measures focus on preventing overpressure rather than maintaining tank pressures as this has already been described throughout the EES documentation and in the response to RFI 71:

(a) Constant monitoring of the pressure in the cargo tanks. Alarms are implemented at defined pressure set points to warn the operator about pressure increase, allowing the operator to take action before release.

(b) Automatic start of the gas combustion unit at a defined pressure set point is also implemented. This means that if there is a pressure build-up triggering high pressure alarms, and no operator action is taken, the gas combustion function onboard the vessel will start before the tank pressure reaches the critical level where gas is released to atmosphere, in order to reduce the tank pressure by gas combustion.

(c) During LNG transfer operations there is an automatic transfer stop on both overflow (i.e. when the max filling levels are reached), and high tank pressures.

19. Roll-over prevention and control is an integral part of the FSRU safety and operational procedures. The FSRU is equipped with both a tank radar system measuring the cargo density at various steps along the liquid height in the tank, and cargo temperature sensors at various tank heights, in order to monitor the cargo and detect indications on stratification. Operational procedures are in place to make sure that LNG is circulated between the tanks if required, to mix the cargo. During LNG loading operations, when new cargo is added to the existing cargo, procedures are in place to ensure the cargo is mixed.

20. Regarding the difference between Mark III membrane tanks on a floating vessel and onshore LNG storage tanks, and especially in terms of roll-over, a major distinction to an onshore tank would be that there always will be external forces (wind/wave motions, vibrations etc.) exerted to the hull and containment system on a floating vessel. This in

contrast to an onshore storage tank where no such forces apply and a very distinct stratification layer may be established. The interfaces between different density layers will be more gradual on a floating vessel such as an FSRU which means that emergency venting as a result of rollovers is less likely to occur. We note that, the level of external forces on a continuously moored FSRU are also somewhat less than for a seagoing LNGC.

21. The proponents note that no catastrophic roll-over events or incidents as reported for onshore tanks have been reported for LNGCs or FRSUs, although some limited pressure build-ups have been experienced on such floating vessels which may have had its origin in roll-over-like phenomena.

[71] Provide clarification on the management of excess Boil-off-Gas when other utilisation options are not available or adequate.

22. The FSRU is equipped with multiple methods of managing boil-off gas:

(c) Increasing tank pressures – The LNG tanks onboard the FSRU can handle a small increase to tank pressures as per design, this pressure build up allows extra time before the boil-off gas has to be managed in other ways.

(d) Gas use by onboard consumers – The FSRU is fitted with generators for onboard electrical demand, these generators are driven by gas combustion engines that utilize the boil-off gas.

(e) Recondenser – The FSRU is fitted with a recondenser in the gas export system. When the FSRU is in gas export mode, the boil-off gas is able to be re-liquified and exported.

(f) Minimum send out (MSO) compressor – The FSRU is fitted with an MSO compressor, this allows for the boil-off gas to be exported to shore when the FSRU is not exporting using the regassification modules.

(g) Gas combustion – The FSRU is fitted with a method of combusting the boil-off gas as a last resort in the event that tank pressures cannot be managed using the above methods. The boil-off gas is combusted to avoid any venting of gas direct to atmosphere.

[72] Provide information (and relevant literature) on the behaviour of formaldehyde and nitrogen oxide as gas and the interactions between the aquatic environments and vegetation the respective plumes intersect.

23. This question is addressed in attachment 2 to this technical note.

[73] Explain how MM-AQ11 will mitigate any deterioration in air quality caused by FSRU air emissions.

24. MM-AQ11 provides as follows: ‘An air quality monitoring programme will be designed and implemented to confirm FSRU emission rates comply within tolerances of the design specifications.’

25. A monitoring program would be developed in consultation with EPA to:

(a) identify suitable sampling locations;

(b) select approved measurement methods for required pollutants;

(c) obtain representative samples;

(d) determine the concentrations of pollutants in the environment or entering the environment from a specific source; and

(e) determine environmental licence compliance.

26. MM-AQ11 will mitigate deterioration in air quality by quantifying FSRU emission rates to ensure they comply with design specifications and impact assessment assumptions. If FSRU emission rates do not comply with design specifications, further assessment will be required to determine any increased risk of emissions. Were this to occur, additional mitigation measures may be required to address unacceptable risks, such as the application of pollution control equipment.

[74] Explain the likelihood of modifying performance of the FSRU to reduce air emissions in the event exceedances are measured.

27. See response to RFI #73 above.

CORRESPONDENCE: N/A

ATTACHMENTS: 2 attachments:

1. AERMOD Publication 1551 Revision 4 November 2014
2. Memorandum concerning behaviour of formaldehyde and NOx as gas and the interactions between the aquatic environments and vegetation.

GUIDANCE NOTES FOR USING AERMOD

Publication 1551 Revision 4 November 2014

1. INTRODUCTION

Schedule C of the State Environment Protection Policy - Air Quality Management [SEPP (AQM)] sets out the minimum requirements for modelling emissions to air and includes specification of the currently approved regulatory model.

The Environment Protection Authority (EPA) of Victoria has approved the US EPA regulatory air dispersion model AERMOD as the replacement for AUSPLUME as the approved regulatory air model for impact assessments in Victoria.

This guideline provides information on the recommended use of AERMOD and is to be used in conjunction with Schedule C of the SEPP (AQM), with the latest version of AERMOD now specified as the currently approved regulatory model.

AERMOD is a steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain, with the modelling system comprising three components:

- AERMOD (dispersion model).
- AERMET (meteorological pre-processor).
- AERMAP (terrain pre-processor).

The basic source and executable codes for the latest approved version of AERMOD (currently version 14134 as of May 2014) and its component pre-processors can be downloaded, at no cost, from the USEPA web site (www.epa.gov/ttn/scram). Commercial versions are also available (see Section 10 below).

Note that AERMOD is not static and evolves to accommodate the best available science. As such, it is the responsibility of the user to ensure that the latest approved version is used.

2. METEOROLOGICAL INPUT FILES

Meteorology is one of the crucial inputs to air dispersion models. Preparation of this key input data needs to be done following recognised and accepted procedures.

AERMOD requires the input of two meteorological files; a 'surface' data file and a 'profile' data file. These files can be provided by a meteorological pre-processor or constructed explicitly.

The EPA Victoria guideline document 'Guidelines for Input Meteorological Data for AERMOD' describes the methods to be used in the construction of the AERMOD meteorological input data files when using AERMOD for air impact assessments in Victoria (EPA Victoria Publication No. 1550).

A period of 5 years of meteorological data should be used, from during the previous 10-year period. The outputs should be shown for each year. A summary table showing the highest and 9^{th} highest predicted values for each year should be produced. The results should demonstrate compliance for each of the 5 years.

This requirement for 5 years of data may be relaxed in special cases, subject to justification. The EPA may approve the use of shorter periods (but never less than 1 year) in cases where (a) the worst case model result using a one year measured dataset is less than 80% of the assessment criterion (in the EPA policy), or (b) some other analysis can be given than shows the period modelled covers a reasonable worst case scenario.

3. CHOICE OF MODELLING DOMAIN

In addition to the requirements listed in Schedule C (Part B No. 5) of the SEPP (AQM), EPA Victoria recommends the use of a uniform Cartesian grid with the following characteristics:

- A domain size (centred on the emission sources) of at least 5 km for non-complex and/or flat terrain, and at least 3 km for complex terrain.
- A grid spacing resolution chosen so that the maximum concentration is not significantly underestimated, and not greater than 100m.

4. TERRAIN INPUT FILES

AERMOD is designed to calculate air pollutant concentrations in all types of terrain, from flat to complex terrain situations, with the AERMAP pre-processor designed to process several types of 'standardised' terrain data to produce terrain elevations for each receptor and source, and a receptor 'hill height scale' for use in complex terrain.

The AERMAP pre-processor has been developed in the USA and as such it is optimised for using standard USA terrain data sources it processes, with the current version supporting processing of US Geological Survey (USGS) Digital Elevation Model (DEM) data, and data from the National Elevation Dataset (NED) in the Geotiff format.

EPA Victoria recommends the use of local topographical data which can be gridded to create a representative terrain input file with a spatial resolution not greater than 90m (or 3 seconds in latitude and longitude). Note that one option is to convert these gridded data into a form that mimics the DEM data format and then use AERMAP to generate terrain input information for AERMOD. The SCRAM web site (http://www.epa.gov/scram001/) provides information on how to achieve this.

Terrain elevation data from the Shuttle Radar Topography Mission (SRTM) can also be processed by AERMAP as they are available in the same Geotiff format as NED data from the USGS Seamless Data Server. This provides an alternative for applications outside the US.

SRTM elevations represent the height of the 'reflective surface' for the radar signal, and therefore include the heights of obstacles such as building and trees. There are data gaps in SRTM data due to the nature of radar reflectivity measurements.

Note that:

- The One-second DEM Project (www.csiro.au/science/One-second-SRTM-Digital-Elevation-Terrain-Model.html) is being undertaken by CSIRO, and the Bureau of Meteorology is currently developing one-second (30m resolution) DEM of Australia based on SRTM data.
- Gap filled and filtered (vegetation and obstacles removed) topography data in high resolution is available from Geo Science, Australia.
- 'Commercial' AERMOD software products are available that allow for conversion of global SRTM3 terrain data files from WebGIS into DEM format that can then be input to AERMAP (see Section 10 below).

5. PREDICTION OF 3-MINUTE AVERAGE CONCENTRATIONS

The basic output from AERMOD is a 1-hour average concentration prediction that is determined using lateral dispersion values for a 1-hour average.

In view of the practical requirement that the approved USEPA version of the AERMOD source code not be modified, any required average predictions different from 1-hour (e.g. 3-minute) need to be based on post-processing of the basic 1-hour average predictions. As such, use of the following formula for converting the 1-hour average concentrations other averaging time values is recommended:

$$c(t) = c(t_0)\,(t_0/t)^{0.2},$$

where (t) is the averaging time (minutes) of interest (3 minutes in this case), and (t_0) is the averaging time consistent with the dispersion rates (60 minutes in this case). The 0.2 factor relates to the generalised dispersion rate in different circumstances, and is set relatively conservatively (typical range 0.17-0.6).

6. MODELLING OF AREA SOURCES

It is recognised that AERMOD concentration predictions for area sources in the current approved version of AERMOD are likely to be overestimated under very light wind conditions (i.e. for wind speeds less than 1 m/s). This issue is addressed in Section 6.2 of the US EPA AERMOD Implementation Guide (www.epa.gov/ttn/scram/dispersion_prefrec.htm#aermod) with various options recommended for avoiding overestimates during such wind conditions. The US EPA intends to develop a revised version of AERMOD to correct this problem.

EPA Victoria recommends that the current latest USEPA approach be adopted until further notice with a volume source approximation used for cases when the key receptors are sufficiently distant from the source.

7. RURAL VS URBAN MODE

AERMOD includes an option for incorporating the effects of increased surface heating from an urban area on pollutant dispersion under stable atmospheric conditions. Only the use of the 'rural' mode is approved by EPA Victoria at this stage.

8. CHOICE OF OTHER OPTIONS

The following options are not to be used without specific approval by EPA Victoria:

- OLM and PVMRM option for modelling conversion of NO_X to NO_2.
- Dry and wet particle deposition options.
- Capped stacks and horizontal sources option.
- Air toxics option.
- Screening mode.

9. SELECTION OF AERMOD OUTPUTS

The output options in AERMOD should be selected in order to assess the impact of emissions to air as specified in Schedule C (Part C) of SEPP (AQM):

- The 'top 100 table' of the model results;
- 9^{th} highest (99.9 percentile) concentration files (plot files) for pollutants having an averaging time of 1 hour or less (see above for post-processing to produce average predictions less than 1-hour);
- Highest (100 percentile) concentration files (plot files) for pollutants having an averaging time of greater than 1 hour).

The following electronic output files should be submitted to, or available to, EPA Victoria:

- Model log file – aermod.out.
- Rank file including top 100 predicted values.
- Plot files (.plt) containing the highest and 9^{th} highest predicted values.
- Exceedence files (frequency of exceedences).
- Time series files for selected discrete receptors.

10. APPROVED VERSION CONTROL

AERMOD has open access to the approved source code in the model, however there are also a number of commercial software packages (with closed source code) marketed by third-party vendors. These software packages include:

- Proprietary GUI's designed to facilitate setting up the inputs for the model and/or analysing the model results, with often no changes to the AERMOD dispersion model kernel that is used by, or embedded within, the GUI.
- Proprietary software marketed as optimised versions of AERMOD that can provide the benefit of reduced runtimes from parallel processing using multiple processors.
- Integrated packages where AERMOD is one of a suite of models and tools within the package.

The EPA will approve the use of any of these provided the basic AERMOD source code has not been modified. The US EPA memorandum 'Clarification on Regulatory Status of Proprietary Versions of AERMOD' (http://www.epa.gov/ttn/scram/guidance_clarificationmemos.htm) addresses the issues regarding the regulatory status of these proprietary software packages and includes the requirement to use test cases to demonstrate equivalency with the approved version.

11. USE OF ALTERNATIVE MODELS

Schedule C (Part A) of the SEPP (AQM) provides for the use of an alternative to the currently approved version of the regulatory model, whereby a proponent for a new or modified source of emissions to air can submit a modelling proposal to EPA Victoria seeking approval to use an alternative model, and demonstrating that the alternative model is appropriate for the circumstances.

The use of AERMOD is preferred wherever possible, but examples of cases where alternative modelling approaches may be allowed are as follows:

1. Complex geographical locations whereby factors such as: terrain, coastal and land-use influences; in combination with the spatial scale of the impact zone of the sources; require the use of fully 3-dimensional meteorological fields. Potential alternative models for such circumstances include:
    - The CALPUFF modelling system (http://www.src.com/calpuff/calpuff1.htm);
    - The prognostic model TAPM (http://www.dar.csiro.au/tapm);
2. Dispersion from source types not adequately modelled by the current version of AERMOD, e.g. Aluminium refineries requiring the use of the buoyant line sources algorithms that are given in the current CALPUFF model.

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Memorandum

To	Independent Advisory Committee	Page	1
CC	Ashurst and Hall & Willcox		
Subject	Crib Point Pipeline and Jetty Works - Response to RFI 72		
From	Belinda Goldsworthy		
File/Ref No.		Date	16-Oct-2020

RFI 72 – Query: Provide information (and relevant literature) on the behaviour of formaldehyde and nitrogen oxide as gas and the interactions between the aquatic environments and vegetation the respective plumes intersect.

Response

Formaldehyde / Vegetation

- Formaldehyde predicted concentrations: Air quality modelling predicted that the maximum 1-hour formaldehyde concentration overland (i.e. where terrestrial plants are situated) will be 30.6 µg/m^3; with a maximum 1-hour concentration of 178 ug/m^3 at the emission source. Deposition rates for formaldehyde are expected to be negligible, and therefore uptake via soil pore water has not been considered a complete exposure pathway.
- Atmospheric fate: Formaldehyde is removed from the atmosphere by direct photolysis and oxidation with photochemically generated hydroxyl (OH) radicals, with a reported half-life ranging from 1.6 to 19 hours in sunlight (USEPA, 2019). Reaction with the hydroxyl radical is considered to be the most important photooxidation process, with end products including water, formic acid, carbon monoxide, and the hydroperoxyl/formaldehyde adduct (WHO, 2002). Therefore, atmospheric formaldehyde is not persistent, and modelled maximum concentrations are likely to remain in the atmosphere for a short period of time, limiting potential exposure to vegetation.
- Atmospheric uptake: plants are known to absorb and metabolise gaseous formaldehyde. Formaldehyde enters plant leaves through stomata and the cuticle, and is more readily absorbed by the abaxial surface and by younger leaves (Giese et al., 1994). When formaldehyde is absorbed, one part of it is oxidised into carbon dioxide in the Calvin cycle while the other is combined into the plant such as amino acids, lipids, free sugars, organic acids, and cell-wall components (Schmitz et al., 2000). Multiple studies have investigated the purification of indoor air via the uptake of formaldehyde by indoor plants (e.g., Kim et al, 2008; Kim et al 2010, Ahu & Montoya, 2011).
- Phytotoxicity potential: The effects of gaseous formaldehyde on plants at concentrations resembling ambient concentrations, including the predicted emission concentrations, are not well known. A summary of published studies examining the acute (short-term) phytotoxicity of formaldehyde is presented in the table below. Consideration of acute toxicity is appropriate given short retention time formaldehyde will have in the atmosphere.
- Summary: In general, mild to no visible signs of injury were observed in plants exposed to concentrations that are predicted to be higher than those for the project (i.e. >150 µg/m^3). When considering these study results and the short retention time in the atmosphere, acute effects from formaldehyde gas emissions to local vegetation is unlikely.

Plant Species	Formaldehyde Concentration(s) tested	Test Conditions	Reported Effects	Source
Common bean (*Phaseolus vulgaris*)	78, 128, 239, and 438 µg/m^3	Exposure for 7 h/day, 3 days/week, for 4 weeks.	• Increased plant leaf areas, leaf dry weight (thicker leaves) and stem dry weight and were taller than control plants. • The most sensitive effect for terrestrial organisms resulting from exposure to formaldehyde in air was an increase in the growth of shoots, but not of roots. • Whilst an imbalance in shoot and root growth may increase the vulnerability of plants to environmental stresses, there were no short-term harmful effects from exposure to these concentrations of formaldehyde.	Mutters et al., 1993
Spider plants	150, 1000 and 10,000 µg/m^3	Exposure for 5 hours	No visible foliar injury was observed at any of the concentrations used.	Giese et al (1994)
Lily (*Lilium longiflorum*)	440 µg/m^3	Exposure for up to 5 hours	Exposure for 1-2 hours reduced pollen tube length by 50-60%, and exposure for 5 hours resulted in no germination.	Masaru et al, 1976
Alfalfa (*Medico sativa*) Spinach (*Spinacia oleracea*) Beets (*Beta vulgaris*) Oats (*Avena sativa*)	840 µg/m^3	Exposure for 5 hours	Mild atypical signs of injury in alfalfa (e.g. foliar lesions) but no injury to spinach, beets or oats	Haagen-Smit et al, 1952

Formaldehyde / Aquatic Environment

- Sea-air exchange: The exchange of soluble gases between the atmosphere and the ocean is controlled by a thin (20-200 µm) boundary layer at the ocean surface and climatic conditions such as wind. There is an efficient transfer of atmospheric formaldehyde into surface water due to formaldehyde's high solubility (Seyfioglu and Odabasi, 2006; USEPA, 2019). Calculations of sea-air exchange have indicated that this process is probably a minor source of formaldehyde in the sea (Mopper and Stahovec, 1986).
- Aquatic environmental fate: In an aqueous environment, formaldehyde is rapidly hydrated to the gem-diol methylene glycol (USEPA, 2019). Formaldehyde will aerobically biodegrade in the aquatic environment, with studies indicating 100% biodegradation in stagnant lake water within 30 hours (USEPA, 2019). Because of its low organic carbon/water partition coefficient (K_{OC}) and high water solubility, formaldehyde is not expected to significantly sorb to suspended solids and sediments in the water column, and therefore exposure to benthic species is considered unlikely (WHO, 2002).
- Bioaccumulation potential: Based on the very low bioconcentration factor of 0.19 (WHO, 2002) and log octanol/water partition coefficient (K_{OW}) estimates of 0.35 (USEPA, 2019) and 0.65

(WHO, 2002), formaldehyde is not expected to bioaccumulate. The USEPA (2019) reviewed experiments performed on a variety of fish and shrimp, which showed no evidence formaldehyde bioaccumulation (Hose and Lightner 1980; Sills and Allen 1979). Moreover, studies of the aquatic food chain found no significant biomagnification (Thomann, 1989).

- Summary: There is a low potential for adverse aquatic impacts from formaldehyde emissions due to formaldehyde's rapid aqueous biodegradation, low potential for bioaccumulation, low potential for accumulation in the benthos and low predicted air concentrations.

NOx / Vegetation

- Nitrogen oxides (NOx) predicted concentrations: Air quality modelling predicted that the maximum 1-hour NO_2 concentration overland (i.e. where terrestrial plants are situated) will be 51 µg/m^3, with a maximum 1-hour concentration of 356 ug/m^3 at the emission source. The modelled maximum NOx air concentrations are expected to occur only 10% of the year. Deposition rates for NOx is expected to be negligible, and therefore uptake via soil pore water has not been considered a complete exposure pathway.
- Atmospheric fate: Nitrogen oxides (NOx) are broken down rapidly in the atmosphere by reacting with other gasses commonly found in the air. The reaction of nitrogen dioxide (NO_2) with chemicals produced by sunlight leads to the formation of nitric acid and reactions with sunlight leads to the formation of ozone (ATSDR, 2002). NO_2 may be considered a good surrogate for NO_X because NO is rapidly converted to NO_2 (USEPA, 1999).
- Plant atmospheric update: Uptake of atmospheric NOx via foliage is the primary exposure mechanism for plants. The reaction of the plant to the nitrogen that arrives at the target site depends on intrinsic plant properties and its nutritional status as well as environmental conditions (WHO, 2000). Uptake of NOx is driven by the concentration gradient between atmosphere and mesophyll (inner leaf tissue) and is typically directly determined by stomatal conductance.
- Phytotoxicity potential: The toxicity of NOx exposure is complex because nitrogen is a macro-nutrient, therefore the addition of nitrogen can result in a physiological response such as the stimulation of growth. Most phytotoxicity studies involving NO_2 exposure were performed using relatively high concentrations (> 190 µg/m^3), which indicate the inhibition of photosynthesis by both NO and NO_2, possibly additively (WHO, 2000). Studies reported short-term exposures (1-7 hours) to NO_2 resulted in the following effects:
    - physiological effects from 190-1100 µg/m^3 NO_2,
    - biochemical effects from 7500 µg/m^3 NO_2; and
    - growth aspects from 2000-3000 µg/m^3 NO_2 (WHO, 2000).

  Most of these impacts were associated with growth stimulation, which is often considered an adverse effect in natural vegetation.
- Summary: the lowest adverse phytotoxic effect reported by WHO (2000) was associated with a concentration of 190 µg/m^3, which is more than two orders of magnitude greater than the 1-hour maximum NO_2 concentration predicted overland for the project. Therefore, given these toxicity study results and the rapid degradation of NOx in the atmosphere, there is expected to be limited phytotoxic impacts (largely associated with the stimulation of plant growth) from the project emissions.

NOx / Aquatic Environment

- Air-water exchange: NO_2 reacts immediately with H_2O when dissolved in water, forming nitric acid (HNO_3). Nitric acid forms nitrate salts when it is neutralised. Thus, NOx and its derivatives exist and react either as gases in the air, as acids in droplets of water, or as salts (USEPA, 1999). The flux of NO_X dry deposition to water is complex and difficult to model (Pryor and Sorensen, 2000).

- Aquatic environmental fate: NO_2 reacts with water within the aquatic environment to form nitric acid, which is very soluble in water. Nitric acid reacts with sea salt (NaCl) particles in marine water to yield sodium nitrate ($NaNO_3$) in the particle phase, with a near total transfer of nitrogens to the particle phase (Pryor and Sorensen, 2000). These particles are likely to be less bioavailable to aquatic organisms than soluble nitric acid.
- Bioaccumulation potential: Nitrogen oxides do not accumulate in the food chain (ATSDR, 2002).
- Summary: There is a low potential for adverse aquatic impacts from NO_X emissions due to its low potential for bioaccumulation, low predicted air concentrations and likely presence as a particulate in marine water with low bioavailability.

References

- Ahu A, Montoya L, 2011. Formaldehyde removal by common indoor plant species and various growing media. *Atmospheric Environment*. 45(16):2675-2682.
- ATSDR, 2002. Nitrogen Oxides (nitric oxide, nitrogen dioxide, etc.), Agency for Toxic Substances and Disease Registry, Division of Toxicology ToxFAQs, April 2002.
- Giese M, Bauer-Doranth U, Langebarthels Ch, Sandermann H, 1994. Detoxification of formaldehyde by the spider plant (*Chlorophytum comosum* L.) and soybean (*Glycine max* L.) cell-suspension cultures. *Plant Physiology.* 104:1301-1309.
- Haagen-Smit AJ, Darley EE, Zaitlin M, Hull H, Noble WM, 1952. Investigation on injury to plants from air pollution in the Los Angeles area. *Plant physiology*, 27:18–34.
- Kim KJ, Kil MJ, Song JS, Yoo EH, Son KC, Kays SJ, 2008. Efficiency of volatile formaldehyde removal by indoor plants: contribution of aerial plant parts versus the root zone. *Journal of American Society for Horticultural Science*. 133(4):521-526.
- Kim KJ, Jeong MI, Lee DW, Song JS, Kim HD, Yoo EH, Jeong SJ, Han SW, Kays SJ, Lim YW, Kim HH, 2010. Variation in formaldehyde removal efficiency among indoor plant species. *Journal of American Society for Horticultural Science*. 45(10): 1489-1495.
- Masaru N, Syozo F, Saburo K, 1976. Effects of exposure to various injurious gases on germination of lily pollen. *Environmental Pollution*, 11:181–188.
- Mopper K, Stahovec WL, 1986. Sources and sinks of low molecular weight organic carbonyl compounds in seawater. *Marine Chemistry*. 19(4):305-321.
- Mutters RG. Madore M, Bytnerowicz, 1993. Formaldehyde exposure affects growth and metabolism of common bean. *Air & Waste*, 43(1):113-116.
- Pryor and Sorensen, 2000. Nitric Acid–Sea Salt Reactions: Implications for Nitrogen Deposition to Water Surfaces. *Journal of Applied Meteorology*, Volume 39, pp.725-731. May 2000.
- Seyfioglu R, Odabasi M, 2006. Investigation of air-water exchange of formaldehyde using the water surface sampler: Flux enhancement due to chemical reaction. *Atmospheric Environment*. 40:3503-3512.
- Schmitz H, Hilgers U, Weidner M. 2000. Assimilation and metabolism of formaldehyde by leaves appear unlikely to be of value for indoor air purification. *New Phytologist*. 147:307-315.
- Thomann RV, 1989. Bioaccumulation model of organic chemical distribution in aquatic food chains. *Environmental Science and Technology*. 23(6):699-707.
- USEPA, 1999. Technical Bulletin, Nitrogen Oxides (NOx), why and how they are controlled, November 1999. https://www3.epa.gov/ttncatc1/dir1/fnoxdoc.pdf. United States Environmental Protection Agency

- USEPA, 2019. Proposed Designation of Formaldehyde (CASRN 50-00-0) as High-Priority Substance for Risk Evaluation, August 2019. United States Environmental Protection Agency.
- WHO, 2000. Air Quality Guidelines – Second Edition, Chapter 11 Effects of nitrogen containing air pollutants: critical levels. World Health Organization.
- WHO, 2002. Concise International Chemical Assessment Document 40: Formaldehyde. International Programme on Chemical Safety. World Health Organization.

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