Supplementary Information to **Section 7.2.6.** Provide a summary of measures considered as best available techniques or technology

**k) Volatile organic compounds emissions control**

Incomplete combustion of fuel within the gas turbines leads to the emission of unburnt hydrocarbons, including volatile organic compounds (VOCs) (Witherspoon, 2021). For an ethane-fired gas turbine these unburnt hydrocarbons are comprised of ethane (approximately 73%) and other VOCs (i.e. formaldehyde, toluene, benzene, and acetaldehyde). The load at which a given gas turbine is operated has a strong effect on the emissions of VOCs, which decrease with increasing load.

VOCs are classified under the *Guideline for assessing and minimising air pollutants* (EPA Publication 1961) as an air toxic. VOCs are chemical compounds based on carbon with a vapour pressure of at least 0.01 kilopascals at 25˚C or having a corresponding volatility under the particular conditions of use. Emissions of VOCs may impact the beneficial uses of the local air environment due to their toxicity, bio-accumulation or odour characteristics. On a regional level, VOCs can be a major contributor to the formation of photochemical smog (AECOM, 2021).

The state of knowledge on VOC emissions from combustion turbines comes from:

1) the US EPA's risk and technology review (RTR) undertaken as part of the turbine maximum achievable control technology (MACT) standard for natural gas fired turbines (US EPA, 2003), otherwise known as the Combustion Turbine MACT; and
2) EPA Publication 929 Managing emissions of volatile organic compounds.

In the US, VOC emissions fall into a category of air pollutants referred to as hazardous air pollutants (HAP) (US EPA, 1977). HAPs include both organic and inorganic compounds in gaseous and solid form.

Although numerous HAPs may be emitted from combustion turbines, only a few account for essentially all the mass of HAP emissions from stationary combustion turbines. These HAPs are: formaldehyde, toluene, benzene, and acetaldehyde (US EPA, 2003). Research undertaken by the US EPA has identified formaldehyde accounting for about two-thirds of the total HAP emissions (US EPA, 2000).

A study undertaken in the US by Carnot Technical Services (1996) found emissions of semi-volatile organic compounds (polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyl (PCB), polychlorinated dibenzodioxin (PCDD), polychlorinated dibenzofuran (PCDF)) from gas-fired utility sources were either not detected or were detected at levels less than 0.001 tons per year.

The Carnot Technical Services (1996) study examined the emissions of formaldehyde and benzene from seven gas-fired turbines. Two of the seven turbines were also examined for toluene. The average concentrations for VOCs (at 100% load) were:

- Formaldehyde – 57.1 $\mu g/m^3$ (77.6% of total VOC measured)
- Toluene – 14.8 $\mu g/m^3$ (20.1% of total VOC measured)
- Benzene – 1.6 $\mu g/m^3$ (2.3% of total VOC measured)

The air quality assessment criteria (AQAC) for the four main VOCs, as defined in EPA Publication 1961, is listed in Table 1.

*Table 1: Table of Health-based AQACs as extracted from EPA Publication 1961*

| Substance | Class | Highly hazardous pollutant | Cumulative/ incremental | Averaging time | AQACs | |
|---|---|---|---|---|---|---|
| | | | | | ppm | µg/m³ |
| Acetaldehyde | 2 | - | Cumulative | 1 hour | 0.3 | 470 |
| Benzene | 3 | Carcinogen, mutagen, highly toxic (chronic) | Cumulative | 1 hour | 0.18 | 580 |
| Formaldehyde | 2 | Carcinogen | Cumulative | 30 min | 0.08 | 100 |
| | | | | 1 hour | | 87 |
| Toluene | 2 | Toxic to reproduction | Cumulative | 1 hour | 4 | 15,000 |

In comparison, in 2004, the US EPA published a MACT standard for natural gas fired turbines with a formaldehyde level of 91 ppb (0.091 ppm or 114 µg/m³). The standard was stayed a few months later and to date is still not in effect (Witherspoon, 2021). A risk and technology review (RTR) was completed by the US EPA in 2020, on the turbine MACT. The RTR retained the 91 ppb level for formaldehyde (Witherspoon, 2021).

The Air Quality Assessment (AECOM, 2021) modelled the total unburnt hydrocarbons emissions (VOCs) from three generators running at 100% load, with an ambient temperature between 5°C and 45°C. The unburnt hydrocarbons comprise ethane + other VOCs (formaldehyde, toluene, benzene and acetaldehyde). Table 2 shows the breakdown of VOC emissions for the Project.

*Table 2: VOC Emissions for Titan 130 Generator Using Ethane Gas at 100% load*

| Compound | VOC Emissions (lb/hr) | VOC Emissions (kg/hr) | VOC Emissions – 3 Generators (kg/hr) |
|---|---|---|---|
| Ethane | 3.6 | 1.63 | 4.89 |
| Other VOCs | 1.3 | 0.59 | 1.77 |
| Total VOCs | 4.9 | 2.22 | 6.66 |

AECOM undertook modelling to determine the ground level concentrations at the Project site and at receptor locations (refer to Attachment 6) for the three generators running at 100% load. This modelling only looked at total VOCs as shown in Table 3. Representative concentrations of individual compounds based on the US EPA analysis for the Other VOCs are:

1) Approximately two-thirds or 66% of Other VOC emissions are formaldehyde
2) The remaining emissions 34% will be made up of predominantly toluene, benzene and acetaldehyde. As benzene is a class 3 air toxic, the conservative approach was to assume the remaining Other VOCs was benzene.

*Table 3: VOC Modelling Predictions at Receptor Locations for Project*

| Receptor | Concentrations (µg/m³) | | | |
|---|---|---|---|---|
| | Total VOC | Ethane[1] | Other VOCs | |
| | | | Formaldehyde[2] | Benzene[3] |
| Onsite (HGP) | 33.1 | 24.2 | 5.9 | 3.0 |
| 1 | 2.1 | 1.5 | 0.4 | 0.2 |
| 2 | 2.5 | 1.8 | 0.4 | 0.2 |
| 3 | 1.5 | 1.1 | 0.3 | 0.1 |
| 4 | 1.6 | 1.2 | 0.3 | 0.1 |
| 5 | 5.9 | 4.3 | 1.1 | 0.5 |
| 6 | 4.7 | 3.4 | 0.8 | 0.4 |
| 7 | 3.2 | 2.3 | 0.6 | 0.3 |
| 8 | 1.8 | 1.3 | 0.3 | 0.2 |
| 9 | 3.1 | 2.3 | 0.3 | 0.3 |
| Background | - | - | - | - |
| Criterion (1-hour) | - | - | 87 | 580 |

Note: [1] ethane concentrations make up 73% of total VOC
[2] based on assumption that formaldehyde concentrations make up 66% of Other VOC emissions
[3] based on assumption the remaining VOC emissions are benzene (34% of Other VOC emissions)

The modelling undertaken by AECOM, has shown ground level concentrations of VOCs to be below the criteria at all gridded, sensitive and industrial receptors (AECOM, 2021).

Under the EPA Publication 1961 *Guideline for assessing and minimising air pollution:*

> *A person whom this Regulation applies must, so far as reasonably practical eliminate the generation of Class 3 substance, and*
>
> *If it not reasonably practical to eliminate the generation of a Class 3 substance, reduce the generation of the Class 3 substance so far as reasonably practical.*

The Combustion Turbine MACT undertook a RTR on HAP emissions (specifically formaldehyde) of 800 lean premix gas turbines operating within the US (US EPA, 2003). The study found that HAP emissions varied as a result of:

1) Sampling and analysis variability
2) Turbine performance
3) Environmental factors (ambient temperature, humidity, atmospheric pressure, background VOC concentrations)
4) Operational factors (fuel quality)

The RTR identified 3 methods for minimising VOC emissions, being:

1) Operational controls to maximise combustion
2) Installation of an oxidation catalyst
3) Alternative fuel

The Project has examined each of these VOC reduction methods as described below.

Operational Controls

Solar Turbines have found that emissions of formaldehyde from their gas turbines, including the Titan 130 (proposed for the Project), are less than the 2004 MACT standard (Witherspoon, 2021). This has been confirmed by the AECOM modelling conducted for the Project.

For benzene (a class 3 substance) it has been estimated that highest ground concentrations of 3.0 µg/m$^3$ will be encountered at the Project site; and between 0.1 and 0.5 µg/m$^3$ at the offsite receptor locations. This estimate is conservative. Based on the studies undertaken by Carnot Technical Services (1996), it is more likely that the benzene emissions are in the order of 2.3% of the Other VOC emissions (or 0.2 µg/m$^3$ at the Project site); instead of the 34% adopted by the Project.

During commissioning, the gas turbines will be calibrated to operate at optimum conditions for ethane gas. The Project will operate three Titan 130 gas-fired turbines. To minimise emissions so far as reasonably practicable the Project has the choice of either operating 1-2 turbines at 100% load, with the third turbine meeting the balancing fuel requirements, or to operate all 3 turbines at a variable load depending on the flowrate of ethane needing to be consumed. Operating at 100% load does minimise VOC production however this requires the "balancing" turbine to rapidly, frequently and substantially swing its load and leads to the requirements for stabilizing burners/pilots to be activated (as part of the burner management system) which in turn leads to much elevated NOx production. By spreading the load changes across all three turbines the entire system operates closer to a steady state and minimises NOx production. Given the very low VOC emissions (5ppm VOC of which 2/3 is formaldehyde per PIL 168 (Witherspoon, 2021)) already and the elevated NOx emissions (~100ppm NOx estimated per discussions with Solar) associated with a 2x100% and 1x "balancing" turbine approach the Project decided to proceed with a configuration that evenly spreads load change requirements across all three machines through programming in the Solar proprietary Supervisory Control System "StationEdge".

Alternative Fuels

The purpose of the Hastings Generation Project is to utilise under subscribed ethane gas that results from natural gas production.

While all the studies referenced above where undertaken utilising natural gas, the US EPA (2003) concluded that fuel switching would not result in significant emissions reductions.

An alternative fuel is not an option for the Project.

Oxidation Catalyst

The top level of VOC control that can be achieved is with an oxidation catalyst. The flue gas exhaust from the turbine would pass through a honeycomb catalyst where the VOC would react with oxygen to form carbon dioxide and water. This type of emission control technology is considered a technically feasible method of reducing VOC emissions. The proposed oxidation catalyst is designed to reduce VOC emissions by approximately 50 - 57%, depending on the fuel, load and ambient temperature.

The Combustion Turbine MACT, concluded that the incremental cost per ton of HAP removed was excessive and have not recommended it. Costs associated with the installation of an oxidation catalyst on the Titan 130 would be approximately $100,000 (USD) for each tonne of VOC emissions removed.

The US EPA (2003) also considered the non-air health, environmental, and energy impacts of an oxidation catalyst system and concluded that there would be only a small energy impact and no non-air health or environmental impacts.

As a result, the Project has chosen to adopt the best available technology of combustion control to minimise VOC emissions.

## References

AECOM. (2021). *Air Quality Assessment - Hasting Generation Project.*

Carnot Technical Services. (1996). *Gas-Fired Boiler and Turbine Air Toxics Summary Report (TR-105646).* Gas Research Institute.

EPA. (2003). *Managing emissions of volatile organic compounds.* EPA Publication 929.

EPA. (2021). *Guideline for assessment and minimising air pollutants.* EPA Publication 1961.

US EPA. (1977). *40 CFR Part 61 - National Emission Standards for Hazardous Air Pollutants*. Retrieved from Code of Federal Regulations: https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-61?toc=1

US EPA. (2000). *AP42, Fifth Edition, Volume 1 Chapter 3: Stationary Internal Combustion Sources. Section 3.1 Stationary Gas Turbines.*

US EPA. (2003, January 14). *National Emission Standards for Hazardous Air Pollutants from Stationary Combustion Turbines*. Retrieved from Federal Register: https://www.federalregister.gov/documents/2003/01/14/03-86/national-emission-standards-for-hazardous-air-pollutants-for-stationary-combustion-turbines

Wien, S., Beres, J., & Richani, B. (2005). *GE Eneregy: Air Emissions Terms, Definitions and General Information.*

Witherspoon, L. (2021). *PIL 168: Volatile Organic Compound, Sulfur Dioxide and Formaldehyde Emission Estimates.* Solar Turbines - A Caterpillar Company.