**ESSO AUSTRALIA PTY LTD**

# Project Alternatives

## Hastings Generation Project

| Rev | Date | Description | By | Checked | Approved |
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| A | 2/09/2021 | Draft | WP | BL | |
| B | 10/09/2021 | For Review | WP | BL | |
| 0 | 11/10/2021 | Issued for Use | WP | BL | NZ |

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# Abbreviations

| | |
|---|---|
| **AEMO** | Australian Energy Market Operator |
| **AFR** | Air Fuel Ratio |
| **BATT** | Best Available Techniques and Technology |
| **$C_2H_6$** | Ethane |
| **CCGT** | Combined Cycle Gas Turbine |
| **CEMS** | Continuous Emissions Monitoring System |
| **$CO_2$** | Carbon Dioxide |
| **$CO_{2e}$** | Carbone Dioxide Equivalent |
| **DELWP** | Department of Environment Land, Water and Planning (Vic) |
| **DLN** | Dry Low NOx |
| **EM** | ExxonMobil |
| **EPA** | Environment Protection Agency (Vic) |
| **ERS** | Environment Reference Standard |
| **g/kWh** | Grams per kilowatt hour |
| **GED** | General Environmental Duty |
| **$H_2S$** | Hydrogen sulphide |
| **HDPE** | High Density Polyethylene |
| **HRSG** | Heat Recovery Steam Generator |
| **km** | kilometre |
| **kWh** | Kilowatt hour |
| **kV** | Kilo Volts |
| **LIP** | Long Island Point |
| **LDPE** | Low Density Polyethylene |
| **MW** | Mega Watt |
| **MWh** | Megawatt hour |
| **$NO_2$** | Nitrogen Dioxide |
| **NOx** | Nitrogen Oxide |

| | |
|---|---|
| **OCGT** | Open Cycle Gas Turbine |
| **PEMS** | Predictive Emissions Monitoring System |
| **PM** | Particulate Matter |
| **ppm** | Parts per million |
| **Project** | Hastings Power Generation Project |
| **SCR** | Selective Catalytic Reduction |
| **SNCR** | Selective Non-Catalytic Reduction |
| **$SO_2$** | Sulfur Dioxide |
| **SOx** | Sulfur oxides |
| **UHC** | Unburned Hydrocarbons |
| **WFR** | Water Fuel Ratio |
| **WHRU** | Waste Heat Recovery Unit |

# 1. Introduction

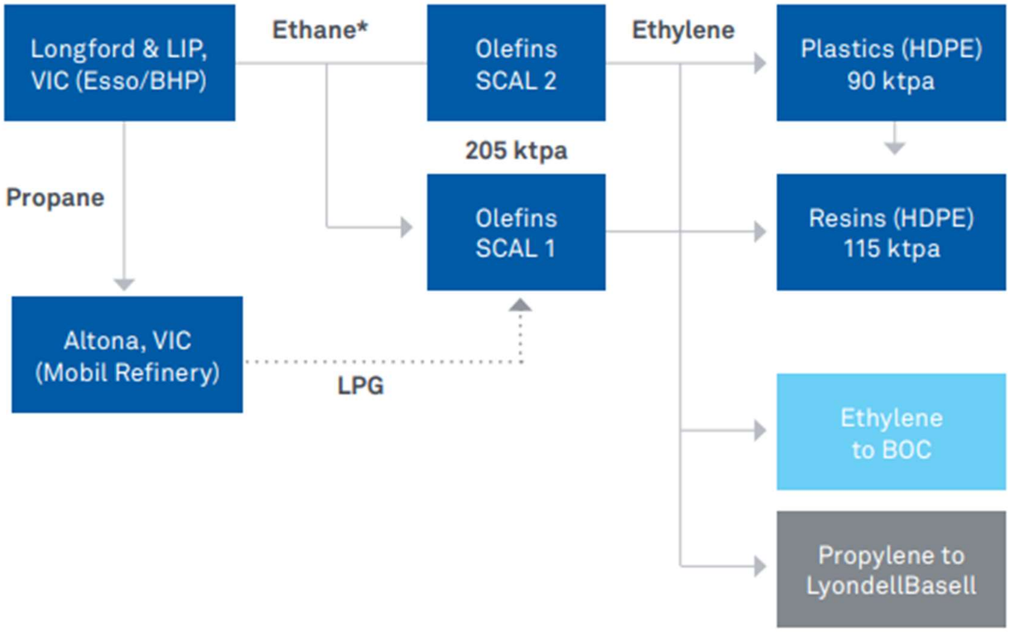
## 1.1. Project Overview

Oil and gas from the Bass Strait field is sent to Longford for processing into crude oil, natural gas and other gas liquids. The natural gas liquids (ethane, propane and butane) are sent to Long Island Point Fractionation Plant (LIP) for further processing prior to LPG being exported via trucks or ships and the ethane being transported via pipeline to a downstream customer in Altona.

The ethane produced at LIP is currently used in the manufacture of detergents and plastics, such as polythene and polystyrene, which in turn are used to manufacture food wraps, bottles, bags, polystyrene foam etc.

Figure 1, outlines the current ethane gas disposition process. Esso's customer announced on 20 May, 2021 that it plans to close one of two ethylene production units by the end of 2021. An alternative use for this under subscribed quantity of ethane is sought. The total quantity of ethane is expected to be less than 190 tonnes per day averaged over a year.

**Figure 1: Current Ethane Disposition**



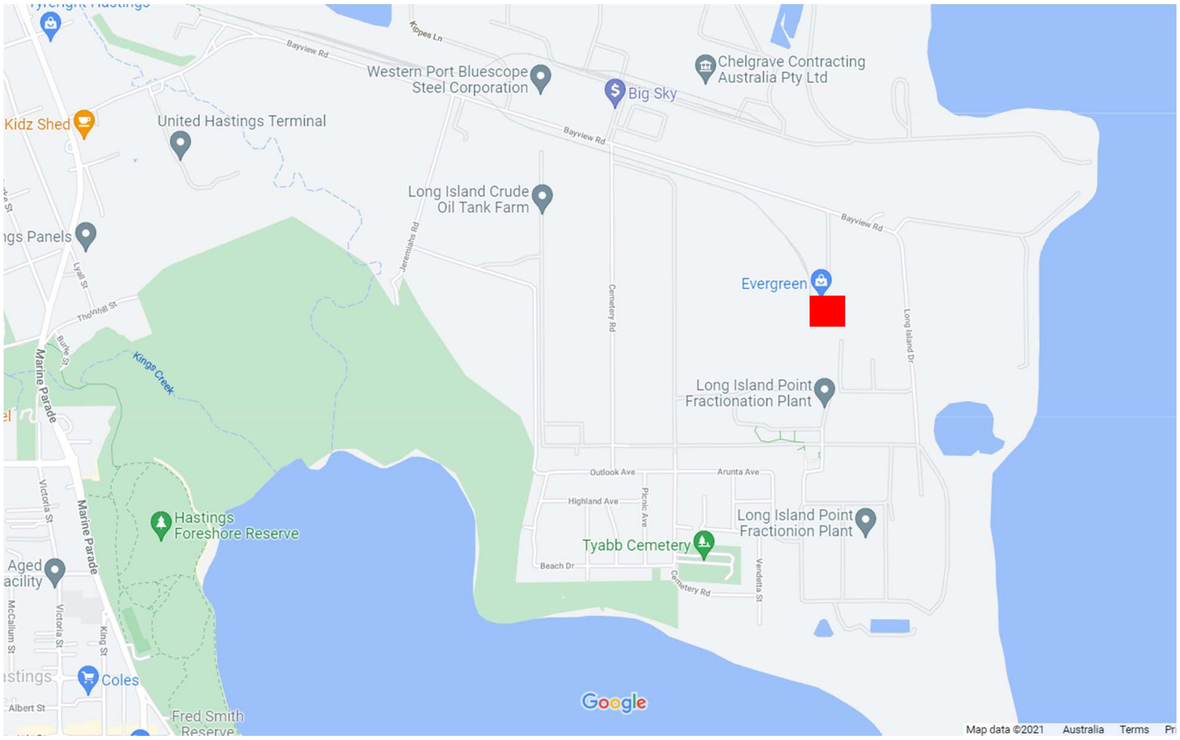
Esso are proposing to install an ethane fired electricity generator on a site adjacent to LIP. This land, which is owned by Esso, is currently being leased for the manufacture of garden supply products such as compost and mulches. Refer to Figure 2.

The project scope, shown in Figure 3, includes the following:

- Install gas turbine generators on the Esso owned land that is currently leased to Evergreen (inclusive of associated equipment such as fuel gas conditioning skids, instrument air compressors, stacks, etc).
- Install associated equipment rooms and electrical infrastructure to enable power export 66 kV power
- Engage United Energy to install additional electrical infrastructure to enable 66 kV power export from the Evergreen site to the Hastings Zone Substation
- Install ethane supply piping from the LIP site to the Evergreen site.

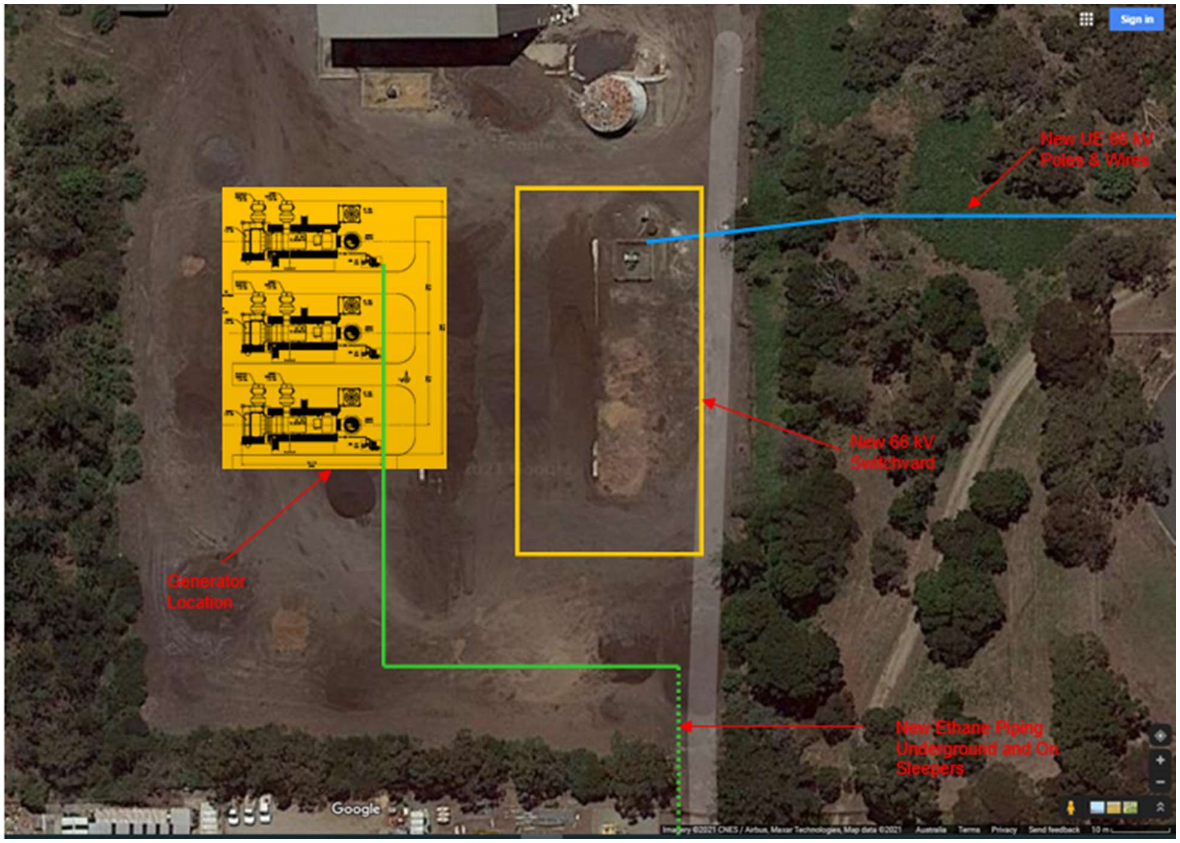
- Install facilities so that the new equipment on the Evergreen site can be suitably operated and maintained (eg. security requirements, crib rooms, offices, etc).
- Modify LIP DMC control systems to minimize operational variability at the generators while ensuring LIP operation/control is not unduly influenced by generator operation.

Figure 2: Location of Ethane Disposition Project



🟥 Project Site

Figure 3: Ethane Disposition Project



## 1.2. Predicted Production Volumes

The Project is anticipated to be in operation from 2023 to 2033 (11 years).

Table 1 provides the expected ethane production volumes over the life of the Project.

Table 1: Ethane Production Quantities over the life of the Project

| Year | Annual Average Ethane to Generators (tonnes/day) | Ethane to Generators (tonnes/year) | Power from Generators (MWh/year) |
|---|---|---|---|
| 2023 | 182 | 66,390 | 282,984 |
| 2024 | 182 | 66,453 | 283,253 |
| 2025 | 168 | 61,368 | 261,578 |
| 2026 | 189 | 69,135 | 294,686 |
| 2027 | 174 | 63,449 | 270,452 |
| 2028 | 95 | 34,744 | 148,094 |
| 2029 | 90 | 32,885 | 140,173 |
| 2030 | 58 | 21,037 | 89,670 |
| 2031 | 50 | 18,317 | 78,074 |
| 2032 | 23 | 8,234 | 35,098 |
| 2033 | 8 | 3,054 | 13,019 |

In addition to the volume of ethane varying from year-to-year, over the life of the project; the volumes are expected to vary from month-to-month, day-to-day and hour-to-hour as driven by natural gas demand and ambient weather conditions. Seasonally the ethane volume will peak in winter, to correspond with the peak in gas demand; and then subsequently falling in summer. This seasonal variation is expected to be in the order of 50 tonnes per day from winter to summer.

The ethane flowrate produced by LIP is variable depending on how the LIP fractionation system operates and what the feed rate is to the LIP fractionation system (an outcome of Longford natural gas liquids production rates). LIP upgrades are being proposed to try to reduce the ethane production variability by smoothing the LIP fractionation system feed rate.

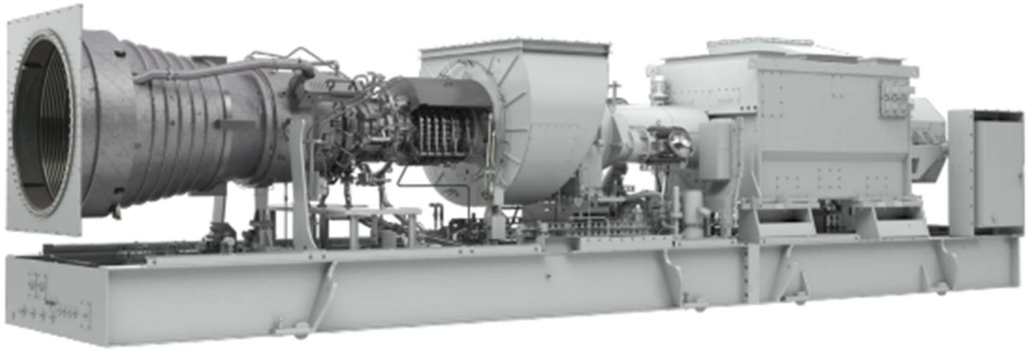
The Project will not be installing any gas storage facilities, therefore any changes in gas volumes and pressure will be experienced at the power plant.

## 1.3. Project’s Proposed Option

The Project is proposing to install:

- three Solar Titan 130 generators, in an open cycle configuration (refer to Section 3.1);
- adopt a lean-mix, dry low NOx control system (refer to Section 4.2); and
- use a continuous emissions monitoring control system (refer to Section 5).

Figure 4: Solar Titan 130



## 1.4. Purpose of this Document

The purpose of this document is to:

- examine the different project alternatives;
- determine the best available techniques and technologies (BATT) to be applied to this Project with respect to turbine selection and emissions control.

This will provide the rationale for the selections made by the Project.

# 2. Alternative Development Options

Currently all ethane gas generated by Esso is sold to a customer in Altona for the production of chemicals and plastics. Due to changing commercial conditions an excess quantity of ethane gas will be generated from 2022 onwards that requires either disposal or reuse.

A number of alternatives have been examined for feasibility, timing, environmental implications and cost. These alternatives include:

1. Increasing ethane consumption either at LIP or Longford.
2. Incorporating a higher percentage of ethane gas into the natural gas, sales gas pipeline.
3. Find an alternative market.
4. Decreasing production of oil and gas in the Bass Strait
5. Reinjection; or
6. Flaring of excess gas at LIP.

## 2.1. Increasing Ethane Consumption within ExxonMobil

Initial studies have shown that LIP can increase its consumption of ethane gas by approximately 20 tonnes per day after undertaking some facility modifications. The Project's gas production figures have taken this volume into account. A further increase of ethane consumption at LIP or Longford is unlikely, and any additional consumption methods will take considerable time to implement and therefore will result in a significant amount of flaring at either LIP or Longford before they could be implemented.

## 2.2. Increasing the Ethane Content of Sales Gas

There is some scope to increase the ethane content of sales gas, and still meet sales gas composition requirements. However, the requirement to blend ethane at a certain rate into the natural gas flow to meet the AEMO required Wobble index criterion means that full disposition of ethane gas cannot be guaranteed.

Additionally, there is currently no method of being able to mix additional ethane gas into the sales gas. To be able to undertake this option a new ethane pipeline and injection facilities would need to be installed between LIP and the sales gas pipeline. The most suitable spot would be at the Dandenong City Gate, blending facility. This would require the construction of a 5-kilometre-long pipeline through urban industrial areas of Dandenong. It would be unlikely that this could be achieved prior to the end of 2024, making this option impracticable given the required start time for alternative disposition of ethane gas.

In addition to scheduling considerations, this option would also present more complex social, cultural, environmental and regulatory considerations. It was concluded that this was not a desirable disposition option.

## 2.3. Alternative Market

This option is a desirable option; however, it is dependent upon sourcing a new market and/or customer. Neither of which have been sourced to-date. Marketing uncertainty makes scheduling for the upcoming need to utilise surplice gas unpredictable.

This option is not viable at this time.

## 2.4. Decreasing Production

The supply of natural gas from the Longford Plant to the state of Victoria is considered to be an essential service under the Essential Services Act 1958, and this will remain the case for the near future. For this essential service to continue there needs to be a continued means of disposing of products that are produced with the natural gas, in this case ethane, butane and propane. If the normal offtake of ethane ceased or was significantly reduced, the ability to continue to produce and deliver natural gas in Victoria at the normal rate would be interrupted. Currently Esso produces 80% of the Victorian gas market.

It is acknowledged that as Victoria moves to Net Zero in 2050, in line with its commitments made under the Climate Change Act (2017); gas production from Bass Strait will cease due to field decline as will the production of ethane.

## 2.5. Reinjection of Ethane Gas

Esso currently, has the ability to reinject surplus gas at the Bream Platform from Longford's Gas Plant 1 when sales gas demand is reduced. However, Longford does not have the capability to remove ethane from the natural gas liquids steam. This process is done at LIP. There is currently no dedicated ethane pipeline running between LIP and the Longford Plant. As such, ethane reinjection is not available.

## 2.6. Flaring

Flaring produces light pollution that could have negative impacts upon wildlife, in particular bird behaviours. Birds that migrate or hunt at night navigate by moonlight and starlight. Artificial light can cause them to wander off course and towards the night-time landscape of cities or other major light sources.

Migratory birds depend on cues from properly timed seasonal schedules. Artificial lights can cause them to migrate too early or too late and miss ideal climate conditions for nesting, foraging and other behaviours[1].

LIP is located close to Western Port Bay, which lies 700 metres to the east and 1000 metres to the south. Western Port is declared a Ramsar Site under the Convention on Wetlands of International Importance Especially as Waterfowl Habitat (Ramsar, Iran 1971). Western Port supports over 30 bird species that are international migrants and listed under migratory agreements with China, Japan and the Republic of Korea[2]. Therefore, continuous flaring at LIP could have an impact on wildlife behaviours in the immediate area.

Community sentiment has been clear on its disapproval of excess flaring at LIP, with incidents being recorded in the media[3]. Flaring also results in greenhouse gas emissions with no commensurate benefit to the community.

Continuous flaring of excess ethane gas will result in Esso exceeding its environmental licence conditions for LIP and would require the Minister (under the emergency provisions) to provide an exemption for flaring until such time as alternatives were made.

Esso is dedicated to minimise its impacts upon the environment and human health as far as reasonably practicable. Continuous flaring does not meet this objective.

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[1] Light Pollution Effects on Wildlife and Ecosystems | International Dark-Sky Association (darksky.org)

[2] DELWP (2017) *Western Port Ramsar Site Management Plan*

[3] Flare up mars plant's anniversary - MPNEWS

# 3. Gas Turbine Options

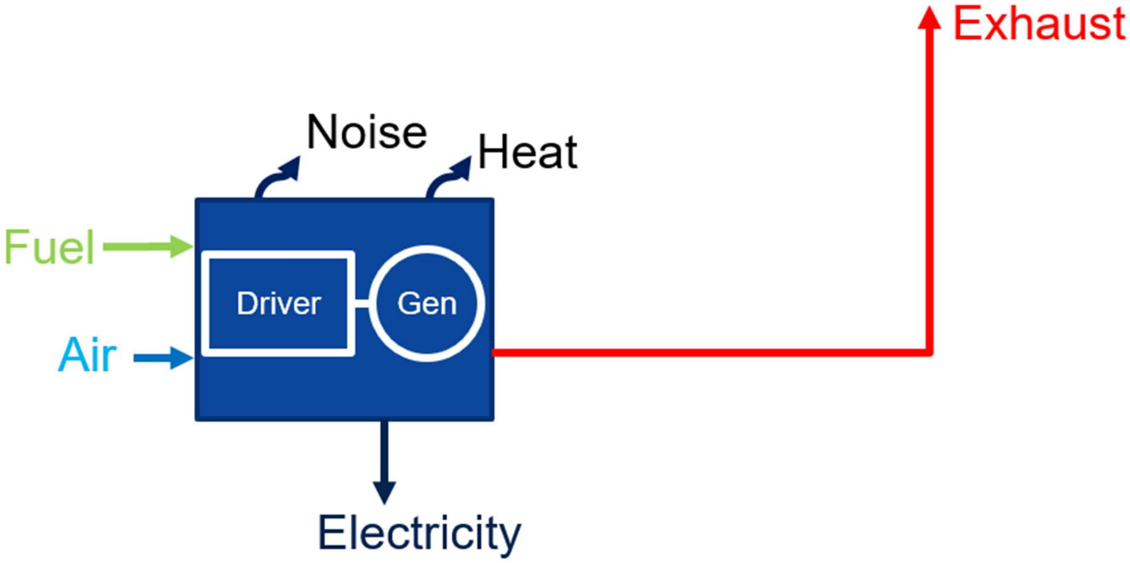
Three gas turbine options were examined, being:

1) open-cycle gas turbines (OCGT);
2) combined cycle gas turbines (CCGT); and
3) cogeneration.

## 3.1. Open Cycle Gas Turbines

The OCGT (sometimes referred to as simple cycle) has a straightforward operation where fresh ambient air and fuel are combined before being injected into the turbine's combustion chamber. The turbine generates electricity and exhaust air is discharged to atmosphere via a stack.

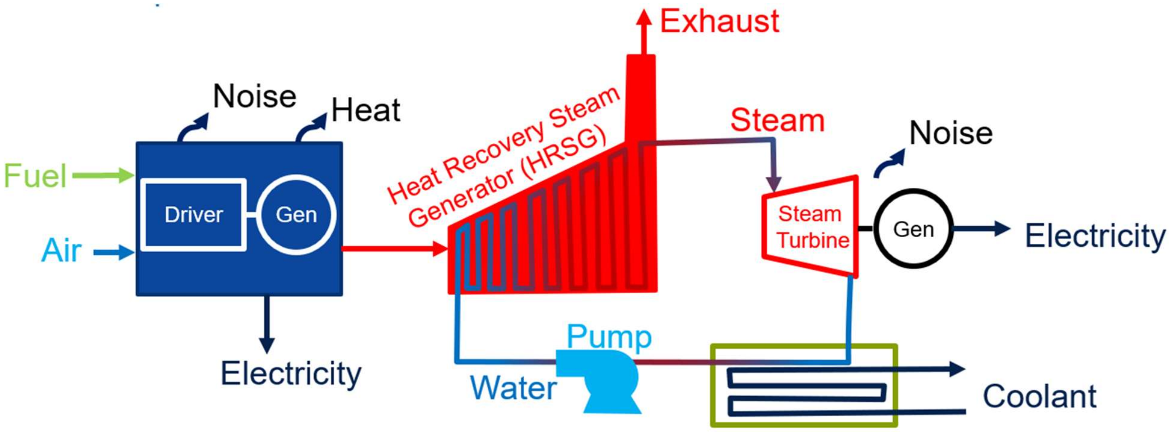
**Figure 5: Open Cycle Gas Turbine**



## 3.2. Combined Cycle Gas Turbines

CCGT is a thermal power plant that combines two types of turbines: a combustion turbine and a steam turbine. Each of these turbines drive a generator that produces electricity or both types of turbines are coupled to the same generator.

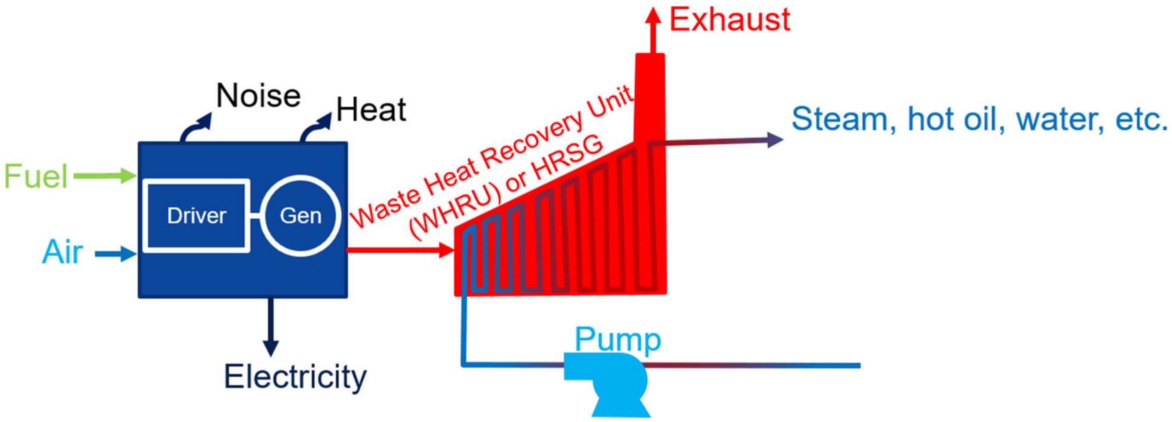
**Figure 6: Combined Cycle Gas Turbine**



## 3.3. Cogeneration

Cogeneration is when the exhaust gases from an OCGT are collected and used to heat either water or oil for use in another process. The remaining residual heat will then be discharged to air. Cogeneration is particularly useful if the facility has a need for steam or heated oil as part of their production process.

**Figure 7: Cogeneration**



## 3.4. Comparison of Gas Turbine Options

Table 2 compares the different attributes of an OCGT and CCGT. Cogeneration was not considered for this Project as LIP does not have a need for additional steam or heated oil.

Table 2: Comparison of OCGT and CCGT

| Criterion | Open Cycle Gas Turbine | Combined Cycle Gas Turbine |
|---|---|---|
| Thermodynamic cycle | Gas turbine generates electricity, with exhaust heat being discharged to atmosphere | Gas turbine generates electricity and waste heat is used to make steam to generate additional electricity via a steam turbine. |
| Availability | Units readily available | Delivery periods significantly longer than OCGT |
| Installation time frame required | Shorter - has the least equipment to install, commission, maintain and operate. | For the required start-up time frame to be met, the installation, by necessity is required to be a 2-stage process, due to the availability of the WHRU.<br>1) OCGT in 2022<br>2) WHRU in 2024 at which time the gas turbines will need to be shut down for retrofitting for 3 periods of 45 days, resulting in 70 tonnes of ethane flared each time (worst case scenario) |
| Capital costs for this Project* | $90 million | $150 million |
| Start-up ramping period to achieve full loading | Less than 30 minutes | 30-180 minutes<br>This may result in flaring while this occurs. |
| Efficiency | 30-35% | 50-60% |
| Emissions intensity for this Project* | 560 g $CO_{2e}$ per kWh | 470 g $CO_{2e}$ per kWh |
| NOx emissions | 25 ppm | 25 ppm ^ |
| Power capacity for this Project* | 40 MW | 48 MW |
| Total power generated over the life of the project | 1,897,084 MWh | 2,163,253 MWh # <br>(an additional 266,169 MWh) |

| Criterion | Open Cycle Gas Turbine | Combined Cycle Gas Turbine |
|---|---|---|
| Flexibility | Very flexible and can ramp up and down very quickly.<br>A requirement for managing the hour-to-hour ethane production swings resulting from market demand for Longford supplied natural gas. | Less flexible. Cannot stop and start as easily as an OCGT.<br>Will be less likely to handle large, sudden fluctuations in gas flow and pressure, resulting in the potential for more NOx emissions. |
| Footprint for this Project* | ~ 1,800 $m^2$ | Sizing will depend on configuration but generally, land requirements for CCGT are twice that of OCGT. |
| Delivery Schedule for this Project* | 2Q 2022 | 4Q 2023 |

Note: * - based on a maximum consumption of 189 tonnes of ethane per day
# - based on being a 2-year delay to install the waste heat recovery unit (WHRU). The extra power generated by the WHRU is equivalent to 1 extra year's operation.
^ - NOx emissions are generated in both the gas turbines and the duct burners of the WHRU.

As noted in Section 1.2, the daily production fluctuations could be significant enough to impact the normal running of the gas turbines. These fluctuations are expected to be short-lived in nature. However, fluctuations in product volumes, pressure and quality have a greater impact on CCGT performance. On the basis of the above analysis, the Project has selected an OCGT design.

# 4. Emissions Control Option

A primary advantage of gas-fired turbines is that they produce relatively less pollution in comparison with coal-fired power plants. Gas-fired turbines do produce nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide ($CO_2$) and small amounts of hydrocarbons.

The technologies used to control air emissions are similar for all drivers, being:

- Exhaust after treatment – refer to Section 4.1
- Combustion control – refer to Section 4.2
- Fuel gas treatment – refer to Section 4.3
- Efficiency improvement – refer to Section 4.4

## 4.1. Exhaust after Treatment

After treatment refers to changing the composition of exhaust gases after the combustion process.

### 4.1.1. Particulate Matter

Particulate matter (PM) filtration is commonly used to reduce particulates on heavier fuels, such as diesel or coal fired machines. A definition for PM can be seen in Table 3.

Table 3: Particulate Matter Definition

| PM Size Designation | Definition | Typical Source |
|---|---|---|
| PM | All solid particles and liquid droplets including $PM_{10}$ and PM2.5 | Various |
| $PM_{10}$ | PM less than 10 microns in diameter, including $PM_{2.5}$ | Crushing and grinding operations, dust from road paving |
| $PM_{2.5}$ | PM less than 2.5 microns in diameter | Motor vehicles, fossil fuel power plants, wood burning |

In general, gas turbines fired on natural gas do not produce significant amounts of PM. Filterable PM from combustion turbines may derive from air borne PM that passes through the gas turbine inlet filters, inert solids in the fuel gas supply, air borne construction debris, metallic rust or oxidation products, or mineral and organic impurities in water used for water injection (if employed).

Condensable PM may consist of sulphates, especially if there is a selective catalytic reduction (SCR) system, and unburned hydrocarbons (UHC) which agglomerate to form particles. Formation of ammonia sulphates from the SCR system in a combined cycle application will also accelerate the corrosion of the heat recovery steam generator (HRSG) tubes downstream from the catalyst, which can contribute to the PM loading.[4]

The Project is not looking to install PM filtration, due to the low volume of PM generated from a gas-fired turbine.

### 4.1.2. Catalytic Systems

Catalytic systems are often used to reduce NOx. There are several types of catalyst options, with each having an applicable range of temperatures and gas composition. These are: 1) selective catalyst reduction (SCR) and 2) selective non-catalyst reduction (SNCR).

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[4] Wien, S. (2009) *Particulate Matter, PM10 and PM2.5: What is it, how is it regulated, how is it measured, and what is GE's position on PM emissions from gas turbines?*

SCR employs a metal catalyst which stimulates a reaction between NOx and added ammonia or urea, reducing the NOx to nitrogen and water. As the temperature of exhaust gases from an OCGT are in excess of 480°C, they are considered too hot for the metal catalyst. Therefore, SCRs are only used on CCGTs. A disadvantage of SCR's is:

Untreated ammonia might slip through the SCR catalyst due to over-injection; this is known as ammonia slip. Ammonia slip can result in human health and environmental issues as a result of uncontrolled release of ammonia into the atmosphere. Table 4 and

- Table 5 outline the effects of ammonia exposure to humans; while Table 6 outlines environmental impacts.
- The catalyst required for reduction is expensive to replace. In gas-fired power plants the catalyst requires replacing around 80,000 hours (9 years) of operation.
- The catalysts are prone to contamination by compounds in the combustion gas.

SNCRs are an alternative method for NOx commonly employed in power plants that burn coal, oil, waste and biomass. SNCRs inject aqueous ammonia or urea into the high temperature flue gases to reduce NOx to nitrogen and water. They can have the same issues as SCR with ammonia slip.

**Table 4: Concentration, Duration and Effect of Ammonia on Human Health**[5]

| Concentration / Time | Effect |
|---|---|
| 10,000 ppm | Promptly lethal |
| 5,000 – 10,000 ppm | Rapidly lethal |
| 700 – 1,700 ppm | Incapacitation from tearing of the eyes and coughing |
| 500 ppm for 30 minutes | Upper respiratory tract irritation, tearing of the eyes |
| 134 ppm for 5 minutes | Tearing of the eyes; eye, nose, throat and chest irritation |
| 140 ppm for 2 hours | Severe irritation, need to leave exposure area |
| 100 ppm for 2 hours | Nuisance eye and throat irritation |
| 50 – 80 ppm for 2 hours | Perceptible eye and throat irritation |
| 20 – 50 ppm | Mild discomfort, depending on whether an individual is accustomed to smelling ammonia |

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[5] The Fertilizer Institute, *Health Effects of Ammonia*

Table 5: Effects of Ammonia Exposure[4]

| Concentration (ppm) | Symptoms | Signs | Consequence |
|---|---|---|---|
| Less than 5,000 | Sting in eyes and mouth, pain when swallowing, hoarseness, tightness of throat, coughing | Reddening of conjunctivae, lips, mouth and tongue, swelling of eyelids, edema of throat | Usually recovery without pulmonary complications |
| 5,000 – 10,000 | Exaggeration of above symptoms, tightness in chest, difficulty swallowing, loss of voice, cough with sputum and sometimes blood | Distress, increase in pulse and respiration rates, swelling of eyelids, burning of mucous membranes | Fatalities due to obstruction of airways |
| Greater than 10,000 | Similar to above symptoms, persistent cough with copious frothy sputum | Shock, restlessness, distress, rapid pulse of poor volume, cyanosis, difficulty breathing | Death as result of asphyxiation; survivors may die later a result of complications |

Table 6: Environmental Impact of Ammonia Releases[6]

| Ammonia in Soil and Air | Ammonia Affecting Plants | Ammonia Affecting Livestock |
|---|---|---|
| Ammonia releases to air with react with moisture to form ammonium, returning to earth in rainfall.<br>Ammonium binds with negatively charged soil organic matter and soil clays.<br>Ammonium rarely accumulates in soil, as bacteria will rapidly convert any not taken up by plant roots, into nitrates.<br>Nitrates can be absorbed by soil or may leach through the soil profile. | A large vapour release of ammonia will likely burn the leaves of nearby downwind vegetation.<br>Ammonia will pull water from the leaves but will not affect the roots. Plants will probably recover long term.<br>Crop yields may suffer loss. | Ammonia vapours are toxic to livestock |

In addition to additional equipment within the power generators, ammonia or urea storage will also be required. For the size of power plant required by this Project, that would necessitate storage greater than 20 tonnes of ammonia. This would trigger the Major Hazards Facilities legislation.

Given the Project's expected fluctuations in ethane supply, there is a greater chance of ammonia slip occurring and the negative impact of ammonia emissions was considered greater than the benefit associated with achieving NOx emissions less than 25 ppm. As such catalytic systems were not considered for this Project.

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[6] Ecological Effects of Ammonia | Minnesota Department of Agriculture (state.mn.us)

## 4.2. Diluted Combustion

NOx emissions are generated during the combustion process. The amount of NOx produced is directly related to the temperature at which combustion takes place. The higher the temperature, the more NOx generated.

Ethane rich feedstock have a higher combustion temperature than a methane rich feedstock, resulting in higher NOx emissions (refer to Section **Error! Reference source not found.**).

Lean combustion is a technique of controlling the combustion to reduce air emissions created. This is typically accomplished by adding a diluent to the air-fuel mixture. The diluent reduces the combustion temperature.

The most common diluent is air, but water / steam and exhaust gas may also be used. Using air dilution in a gas turbine is called “dry low NOx” (DLN). The use of water dilution is called “wet low NOx” (WLN).

Dilution of the air-fuel mix reduces the machine’s ability to adjust to large or fast changes in fuel composition, ambient temperature and load. Air emission rates may significantly increase with low loads (less than 60%) and low ambient temperatures (less than 0°C).

The Project examined DLN and WLN systems and these are discussed in Section 4.2.1 and 4.2.1, below.

### 4.2.1. Dry Low NOx

In a conventional combustor, the fuel and air are introduced directly into the combustion zone; and fuel/air mixing and combustion take place simultaneously. Under this scenario wide variations in the air to fuel ratio (AFR) exist and combustion of localised fuel rich pockets produce significant levels of NOx emissions.

In a DLN system, the air and fuel are premixed in a very lean AFR prior to being introduced into the combustion zone. The excess air in the lean mixture acts as a heat sink, which lowers combustion temperatures. Premixing results in a homogenous mixture, which minimises localised fuel-rich zones.

To achieve NOx levels below 50 ppm the design AFR approaches the lean flammability limit. To stabilise the flame, ensure complete combustion, and minimise CO emissions, a pilot flame is incorporated into the combustor. The relatively small amounts of air and fuel supplied to this pilot flame is not premixed and the AFR is nearly stoichiometric, so the pilot flame temperature is relatively high. As a result, NOx emissions from the pilot flame are higher than from the lean premixed combustion.

The proposed Titan 130 has been shown to produce emissions in the range of 25 ppm NOx under normal operating conditions, including the use of the pilot flame.

### 4.2.2. Wet Low NOx

Injecting water into the flame area of a turbine combustor provides a heat sink that lowers the flame temperature and thereby reduced thermal NOx formation.

Water purity is essential to prevent or mitigate erosion and/or the formation of deposits in the hot section of the turbine.

Water to fuel ratio (WFR) is the most important factor affecting performance of wet controls. NOx reduction efficiency increases as the WFR increases. Turbines can achieving a reduction efficiency of 60-90 percent in NOx emissions where WFR are greater than 0.42. However, many turbines show an increase in CO and unburnt hydrocarbon (UHC) emissions as the WFR increases, especially above 0.8[7].

The type of fuel affects the performance of wet controls. The fuel-based nitrogen content also affects the performance of wet controls. Fuels with relatively high nitrogen content, such as residual oils, result in significant fuel NOx formation. As wet controls only serve to lower the flame temperature, they are only effective in controlling thermal NOx formation and not fuel NOx formation. As the Project is burning

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[7] US EPA (1993) *Alternative Control Techniques Document – NOx Emissions for Stationary Gas Turbines* (EPA-453/R-93-007)

ethane gas this is not a significant issue. Ethane is a low-nitrogen fuels, consequently, fuel NOx formation is minimal when they are burnt.

Wet controls affect gas turbine performance in two ways – power output increases and efficiency decreases. The energy for the added mass flow and heat capacity of the injected water can be recovered in the turbine resulting in an increase in power output. While the fuel energy required to vaporise water in the turbine combustor results in a net penalty to the overall efficiency of the turbine. The below table provides an example of performance changes.

**Table 7: Example of Turbine Performance Changes as an Effect of Water Fuel Ratio**

| NOx ppm | Water/Fuel Ratio | Percentage overall efficiency change | Percentage output change |
|---|---|---|---|
| 25 | 1.2 | - 4 | + 6 |

Water injection increases the dynamic pressure oscillation activity in the turbine combustor. This activity can, in some turbine models, increase erosions and wear in the hot section of the turbine, thereby increasing maintenance requirements. For example, in some turbines the standard inspection interval is 8,000 hours, with WLN that may be reduced to 6,500 hours.

### 4.2.3. Emissions Control Selection

Table 8 compares the two types of emission's control that were evaluated for this Project.

**Table 8: Comparison of Air Emissions Control Equipment for Project**

| Criteria | No NOx Control | Dry Low NOx | Wet Low NOx |
|---|---|---|---|
| NOx | 99-450 ppm^ | 25 ppm | 25 ppm |
| Water usage | 0 L / MW | 0 L / MW | 150 L / MW # |
| Maintenance Inspections | | 8,000 hours | 6,500 hours |

Note: *

\# Based on 40MW, the Project is expected to consume approximately 50 ML/year of water

^ Source – US EPA (1993) Alternative Control Techniques Document – NOx Emissions for Stationary Gas Turbines (EPA-453/R-93-007)

DLN is considered the best available technology to reduce NOx emissions for an OCGT.

WLN usually have higher CO emissions when operating at lower loads and increased gas turbine service intervals and therefore an increased risk of early overhaul and reduced performance/efficiency.

Water for the Project would be sourced from the mains water supply. For a power plant of 40 MW, the Project would need approximately 50 ML of demineralised water each year. The Project examined alternative sources of water, for example reusing stormwater runoff from LIP. However, this proved to be an insufficient volume of water (approximately 5 ML/year) to meet the Project's needs. In addition, stormwater is an unreliable supply.

The Project has chosen to adopt DLN technology.

## 4.3. Fuel Treatment

Fuel treatment for emissions reduction is focused on the reduction of hydrogen sulphide ($H_2S$) within the gas to minimise the production of sulphur oxides (SOx). Sour gas is treated at LIP prior to entering the pipeline to the power plant. Table 9 (ethane gas composition), shows that the sweet gas delivered to the power plant has negligible quantities of $H_2S$ (0.00001%).

Further $H_2S$ removal, prior to combustion is not required.

## 4.4. Efficiency and Emissions Reduction

Reducing the amount of fuel directly translates to a lower exhaust flow rate. Therefore, the higher the efficiency of the equipment and work practices can translate to lower air emissions. This is highly beneficial when trying to extend the life of project with a fixed fuel quantity. However, for this Project the quantity of gas available will vary in accordance to the field production rates and how much will be consumed within LIP prior to transporting to the power plant. The total quantity of $CO_2$ emission will not be reduced by improving efficiency, only the emissions intensity.

This Project is looking to generate a maximum of 40 MW, with an average of 20 MW over the life of the project. AEMO[8] have recorded that as of July 2021, Victoria has 7,298 MW of power being produced from fossil fuel fired power plants, or 52% of the total electricity produced in Victoria, currently. A further 3,890 MW is in the planning process, making a total of 11,188 MW of fossil fuel derived electricity. This Project would represent a 0.36% increase in the total existing and planned fossil fuelled power produced in Victoria, at its peak; and 0.09% of the total electricity generated (renewables and non-renewables). By adding a waste heat recovery unit onto the gas-fired turbine, this Project's contribution to the state's electricity will increase to 0.4% (an 0.04% increase).

As discussed in Section 3.4, the Project is proposing to install OCGT as the base case.

## 4.5. Gas Composition

Traditionally gas turbines have run on natural gas. As such, turbine performance characteristic and specifications; and emission standards are based on natural gas feedstock.

Natural gas, provided to Victorian households is a mixture of multiple gases, with methane content being more than 90 percent. The remaining gases can be ethane ($C_2H_6$), propane ($C_2H_8$), nitrogen ($N_2$), carbon dioxide ($CO_2$) and even hydrogen sulphide ($H_2S$).

This Project, will be using an ethane rich fuel for the gas-fired turbines. This ethane is a by-product of natural gas and crude oil production and the composition of ethane to be supplied to the power plant is detailed in Table 9.

**Table 9: Composition of LIP Ethane Supply**

| Component | Composition (%) |
|---|---|
| Methane ($CH_4$) | 0.56 |
| Ethane ($C_2H_6$) | 99.1 |
| Propane ($C_3H_8$) | 0.35 |
| i-Butane ($C_4H_{10}$) | 0.001 |
| Sulphur Dioxide ($SO_2$) | 0.0001 |
| Total | 100.00 |
| LHV ($MJ/m^3$) | 59.02 |

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[8] AEMO | Generation information

### 4.5.1. Combustion

Ethane is more reactive than natural gas, which might lead to a greater risk of combustion dynamics, flame flashback, or increased NOx emissions.

### 4.5.2. Flashback

In a lean, premixed combustion system, flashback can occur when transient conditions allow the local flame speed to exceed the local air velocity and the flame is able to propagate upstream from the combustion zone into the pre-mixer or fuel nozzle. When this happens metal temperatures may increase to unacceptable levels and hardware damage may occur. In severe cases, the damage may lead to a forced outage.

Using higher molecular weight hydrocarbons, such as ethane, can create additional risks for flashback as the laminar flame speed (or the speed at which the flame propagates upstream into the unburned fuel) is higher than that of methane.

To overcome this a pilot flame is installed between the pre-mixer and the combustion chamber to prevent flashbacks reaching the pre-mixer.

The Titan 130 gas turbines typically route 4%-6% of their fuel supply to a continuously operating pilot flame within the machine main burner/s. At these levels, the emissions from the turbines meet the 25 ppm CO and 25 ppm NOx. Maintaining ethane supply flowrate rates of change to within 1 tonne per day per second will ensure that the pilot operation does not significantly impact emissions performance.

### 4.5.3. Combustion Dynamics

Small changes in fuel/air concentrations can cause fluctuations in the flame's heat release rate, which lead to pressure oscillations. Shifts in fuel heating values may trigger combustion dynamics in some combustion systems. The potential for combustion dynamics can be higher in lean-premixed combustion systems (relative to diffusion flame systems) as there can be large changes in heat release for very small changes in AFR. If left unchecked, these instabilities may impact gas turbine operability, and in worse-case scenarios, may cause degradation or damage to combustion hardware.

The Titan 130 gas turbine generators are typically operated to provide a base load power however they have the functionality to self-regulate fuel gas feed rate and fuel gas feed pressure as needed. Given this the generators will be set to generate maximum power output (13.5 MW per machine) and they will consume as much ethane is required, given ambient temperature conditions, to achieve this. Where LIP produces more ethane than can be consumed by the three gas turbines then the pressure in the new ethane piping will increase until the ethane is flared at LIP via pressure let down valve. Where LIP produces less ethane that can be consumed by the gas turbine generators then the pressure in the new ethane piping will fall until the gas generator starts to self-regulate its power output to ensure a minimum ethane fuel gas pressure is maintained.

### 4.5.4. Emissions

Operating on a more reactive fuel can increase flame temperature. Depending on the level of increase and gas turbine combustion configuration, this can impact NOx emissions.

With the increasing number of shale gas wells in production worldwide, there is an increase demand to fuel gas turbines with gases other than natural gas, in particular ethane. Solar have undertaken research into operating their turbines with ethane, analysing performance characteristics in laboratory test rigs and engines, and are confident that they can achieve an average NOx emission rate of 25 ppm.

# 5. Emissions Monitoring System Option

As detailed in the *Guidelines for assessing and minimising air pollution in Victoria*[9], assessing different air pollutants and quantifying their emissions rates can be a technically complex task.

Continuous emissions monitoring systems (CEMS) are considered to be best practice for the measurement of emissions from stationary sources. As such the Project will be adopting a CEMS system in each stack.

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[9] EPA (2021) *Guideline for assessing and minimizing air pollution in Victoria*; EPA Publication 1961

# 6. Greenhouse Gas Emissions

Presently ethane gas is used to produce ethylene. Ethylene is then converted into polyethylene and then plastics. Over the life of plastics made from fossil fuel feedstocks, it is estimated that 4.3 tonnes of $CO_{2e}$ is emitted per tonne of plastic[10] generated. Qenos[11] have indicated that for every tonne of ethylene produced one tonne of plastics and resins is generated. Based on this data, Table 10 compares the greenhouse gas emissions from the current use of ethane to power generation from ethane, noting that electricity generation produces less greenhouse gas emissions than plastics manufacture.

Table 10: Comparison of Greenhouse Gas Emissions

| Ethane Production (t/year) | Power Generation | | Plastics | | |
|---|---|---|---|---|---|
| | Power Generated (MWh/year) | GHG Emissions (t $CO_{2e}$/year) | Ethylene* (t/year) | Plastics LDPE + HDPE (t/year) | GHG Emissions (t $CO_{2e}$/year) |
| 69,135 (max) | 294,686 | 195,652 | 55,308 | 55,308 | 237,824 |
| 40,461 (av) | 172,462 | 114,503 | 32,369 | 32,369 | 139,187 |
| 445,066 (total) | 1,897,084 MWh | 1,259,536 tonnes | 356,053 tonnes | 356,053 tonnes | 1,531,028 tonnes |

Note: * Approximately 800 kilograms of ethylene is produced from each tonne of ethane gas[12].

Table 11 shows that the lifecycle emissions intensity of electricity production is lower than plastics per tonne of ethane.

Table 11: Emissions Intensity

| | Power Generation | Plastics Manufacture |
|---|---|---|
| Greenhouse gas emissions (t CO2e / t ethane) | 2.83 | 3.44 |

Gas-fired turbines generate less greenhouse gases than traditional coal-fired generators. An examination of National Greenhouse and Energy Report (NGER) data shows that the Latrobe Valley coal-fired power stations are generating, on average, 1.36 tonnes of $CO_2$ for each megawatt of electricity produced. While the Project is expected to produce 0.66 tonnes of $CO_2$ per megawatt.

Table 12, compares the amount of greenhouse gas emissions from the ethane fired gas turbines against emissions from current electricity providers and ethane use.

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[10] Pilz, H. et al (2010) The impact of plastics on life cycle energy consumption and greenhouse gas emissions in Europe Microsoft Word - Final_Summary_Denkstatt _Vers.1.3 _ September2010.doc (plasticseurope.org)

[11] Qenos (2018) *Qenos Altona Safety Case Summary* [Qenos Altona Safety Case 2018.pdf]

[12] Department of Industry, Innovation and Science (2019) *Australian Industry Verification Report, Case Number 515: Qenos Pty Ltd*

**Table 12: Greenhouse Gas Emissions based on Maximum Production Rate of 189 tonnes of Ethane per day**

| Product | Throughput (t/ day) | Throughput (t/ year) | Emissions Intensity (t CO2/ t product) | Electricity (MW/year) | Emissions Intensity (t $CO_2$/MW) | Emissions (t $CO_2$/ year) |
|---|---|---|---|---|---|---|
| Ethane | 189 | 68,985 | 2.83 | 294,686 | 0.66 | 195,228 |
| Coal |  |  |  | 294,686 | 1.36 | 400,773 |
| Ethylene | 151* | 55,188 | 2.15^ |  |  | 118,654 |

Note: * Approximately 800 kilograms of ethylene is produced from each tonne of ethane gas, therefore for 189 tonnes of ethane 151 tonnes of ethylene will be produced.

^ Emissions intensity is calculated from Qenos NGER annual report of 978,936 tonnes of $CO_2$ generated for 455,000 tonnes of ethylene produced[13].

At the Project's peak, it will replace 119 kt of $CO_2$ per year from ethylene production and 401 kt of $CO_2$ per year from coal fired power stations. Thereby resulting in a net reduction of 324 kt of $CO_2$ per year.

As part of ExxonMobil's general environmental duty (GED), there is a desire to minimise emissions as far as possible and maximise efficiency. Installing a WHRU onto the OCGT will not reduce emissions generated. The Project's objective is ethane disposition.

## 6.1. Emissions Targets

Under the Climate Change Act (2017), Victoria has set the following emissions reduction targets, based on 2005 emissions:

- 28-33% by 2025
- 45-50% by 2030
- net zero by 2050

Victoria's emissions in 2019 were 24.8% below 2005 emissions[14], exceeding the 2020 target of 15-20 percent reduction on 2005 emission values.

The Project is expected to operate for 11 years, ceasing in 2033. It will peak in 2026, then significantly slow down production from 2028 onwards.

The Project will not be a significant contributor (0.2 percent[15] at its peak) to Victoria's greenhouse gas emissions[16]. Nor should it impact Victoria being able to meet its emission reduction targets, as the Project is expected to provide a net benefit in greenhouse gas emissions to Victoria, as discussed above.

As the site will generate greater than 25,000 tonnes of $CO_{2e}$ per year, the operation will be reporting under the National Greenhouse and Energy Reporting system.

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[13] Corporate emissions and energy data 2019-20

[14] Victoria's greenhouse gas emissions (climatechange.vic.gov.au)

[15] Based on Victoria's 2019 Greenhouse Gas Inventory of 91.3 million tonnes of $CO_{2e}$

[16] State Greenhouse Gas Inventory (climatechange.gov.au)