Petrojarl Rosebank FPSO BAT Assessment (PPC/123)

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Project Title: **PPC Permit Application Support**
Document / Rev No.: 217505C-003-RT-6200-0001/2
Date: April 2026

Rev	Date	Description	Issued by	Checked by	Approved by	Client Approval
0	19/12/2025	Issued for Client Use	[redacted]	[redacted]	[redacted]	[redacted]
1	19/02/2026	Issued for Internal Review	[redacted]	[redacted]	[redacted]	[redacted]
2	17/04/2026	Issued for Client Use	[redacted]	[redacted]	[redacted]	[redacted]

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ABBREVIATIONS

AIP	Altera Infrastructure
AQS	Air Quality Standards
BAT	Best Available Techniques
BATc	BAT Conclusions
BEIS	Business Energy and Industrial Strategy
BREF	BAT Reference Document
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DESNZ	Department for Energy Security and Net Zero
DLE	Dry Low Emissions
ELVs	Emission Limit Values
ESOS	Energy Saving Opportunity Scheme
FPSO	Floating Production Storage and Offloading
FWP	Fire Water Pump
GTG	Gas Turbine Generator
H_2S	Hydrogen Sulphide
HEPA	High Efficiency Particulate Arrestance
IED	Industrial Emissions Directive
IGG	Inert Gas Generator
ISO	International Organization for Standardisation
KPI	Key Performance Indicator
LCI	Large Combustion Installation
LCP	Large Combustion Plant
LP	Low Pressure
MAT	Master Application Template
MCP	Medium Combustion Plant
MMSCF	Million Standard Cubic Feet

MOC	Management of Change
MRO	Maximum Rated Output
MS	Management System
MW	Megawatts
MW_{th}	Megawatt (thermal)
NMVOCs	Non-Methane Volatile Organic Compounds
NO_2	Nitrogen Dioxide
NO_x	Nitrogen Oxides
OEM	Original Equipment Manufacturer
OPRED	Offshore Petroleum Regulator for Environment and Decommissioning
OTNOC	Other Than Normal Operating Conditions
PfS	Power from Shore
PIL	Solar Turbine Product Information Letter
PPC	Pollution Prevention and Control
PPC Regulations	The Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 2013 (as amended)
SAP	Systems, Applications, and Products in Data Processing
SAT	Subsidiary Application Template
SCR	Selective Catalytic Reduction
SONO	Start of Normal Operations
SP E&P	Siccar Point Exploration and Production
SRU	Sulphur~~ate~~ Removal Unit
SO_x	Oxides of Sulphur
UHCs	Unburnt Hydrocarbons
UKCS	United Kingdom Continental Shelf
VRU	Vapour Recovery Unit
WoSPS	West of Shetland Pipeline System
WHRU	Waste Heat Recovery Unit

1.0 INTRODUCTION

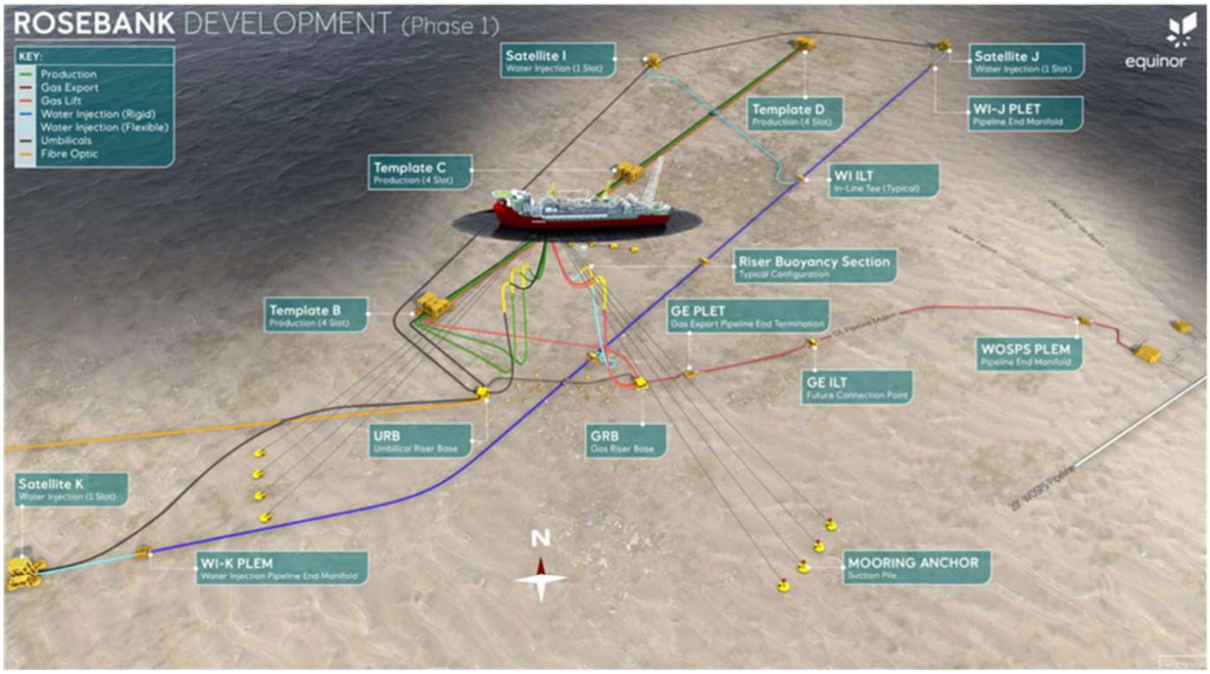
This Best Available Techniques (BAT) assessment considers options and techniques to prevent and minimise significant environmental impacts associated with the provision of main power and heat requirements on the Petrojarl Rosebank Floating Production Storage and Offloading (FPSO) installation deployed to the Rosebank Field. This report provides an update to the conclusions presented in the previous BAT Assessment [15] developed during the concept select phase, specifically focussed on the application of BAT across the main combustion plant. The assessment is required under the Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 2013 (as amended) [1], which transposes the Industrial Emissions Directive 2010/75/EU (IED) [2], as part of the permit application and supports the Rosebank PPC Permit application [3].

1.1 Project Overview

The Rosebank Production Installation (FPSO (Floating, Production, Storage and Offloading)) is owned by the company Knarr LLC, a wholly owned subsidiary of Altera Infrastructure FPSO Holdings Limited (Company House number SC750716) and a wholly owned indirect subsidiary of Altera Infrastructure LP, the parent entity of the Altera Infrastructure group of companies. The installation operator and duty holder is Golar-Nor (UK) Limited, a subsidiary of Altera Infrastructure and this BAT assessment has been prepared on their behalf.

The Rosebank Field is located approximately 130 km north-west of Shetland, in the Faroe-Shetland Channel on the north-west edge of the UK Continental Shelf (UKCS). It spans blocks 213/26b & 213/27a (license P1026), block 205/1a (license P1191) and block 205/2a (license P1272), at a water depth of approximately 1,100 m. The Rosebank prospect was first discovered in 2004 (See

Figure 1-1 Rosebank Field Location



, Figure 1-3 and Figure 1-3 below). Adura Operations Limited will operate the field under a joint venture agreement with Ithaca Siccar Point Exploration and Production (SP E&P) under an 80/20 split.

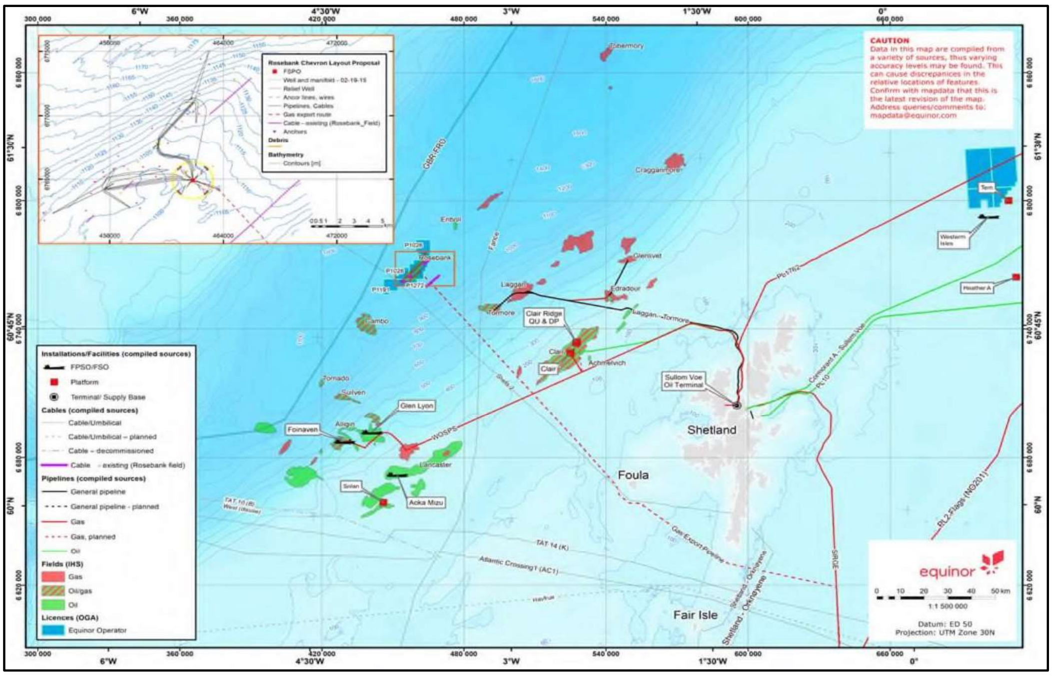


Figure 1-1 Rosebank Field Location

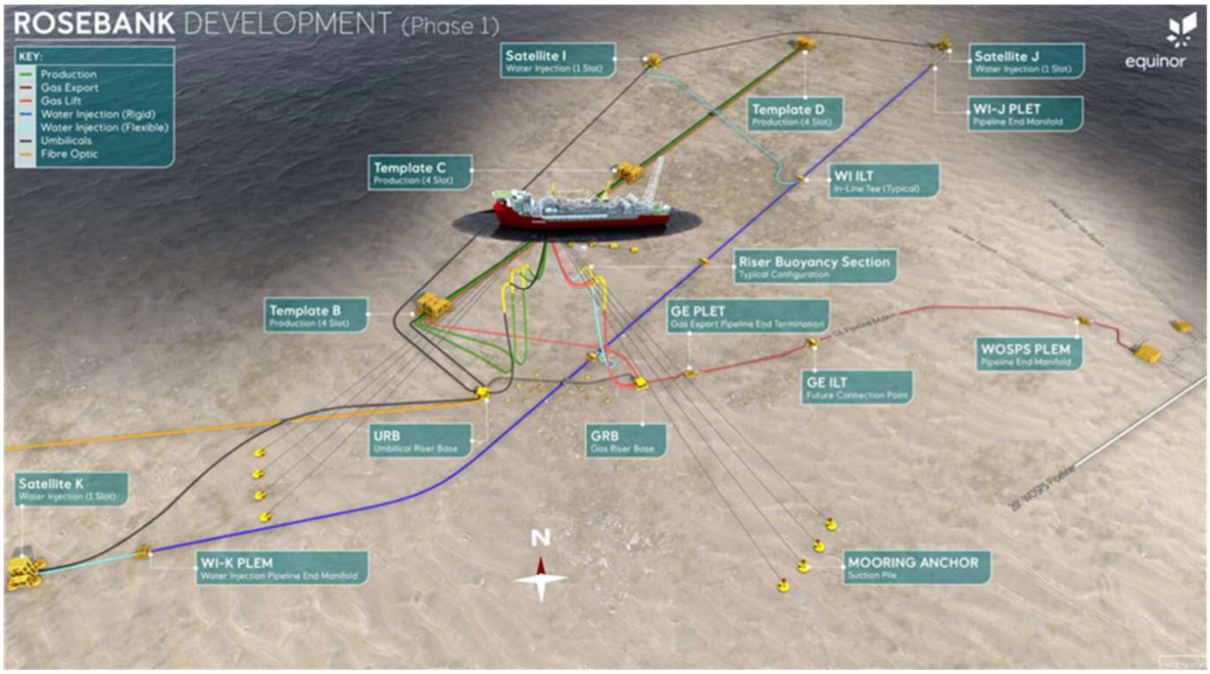


Figure 1-2 Rosebank Field Development Arrangement

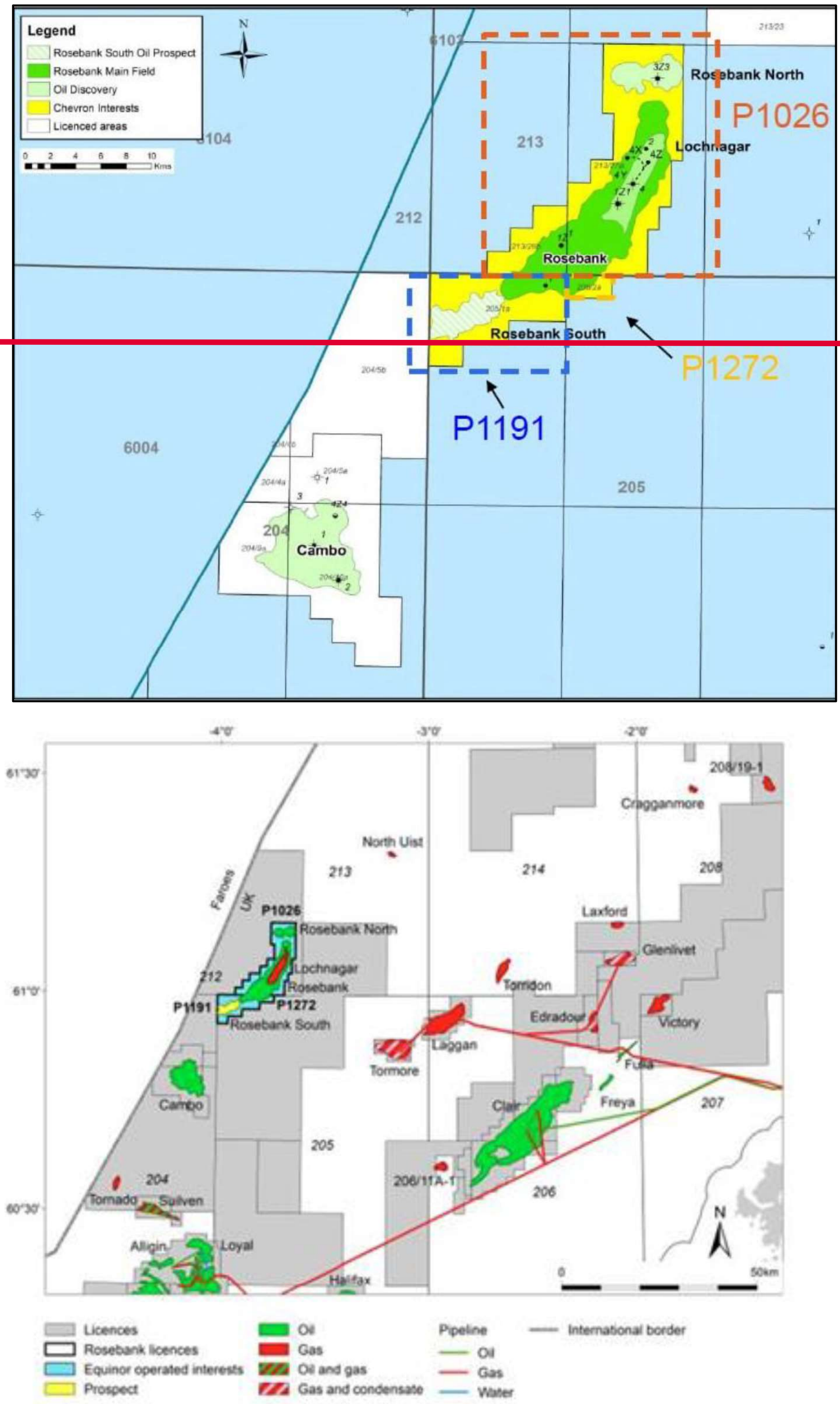


Figure 1-3 Rosebank Licences

The licensees shall develop the Field with subsea production and water injection wells (four production and 3 water injection wells during initial phase of development) tied back to a lease and operate FPSO where the produced liquid and gas streams will be processed. The FPSO turret is located at coordinates Latitude 60°59'58,067"N, Longitude 3°46'25,425"W, ED50.

Produced oil will be stored in the FPSO and transported via shuttle tanker to refineries. The associated gas will be used as fuel gas and for gas lift, while remaining gas will be exported via an export pipeline to the existing West of Shetland Pipeline Systems (WoSPS). When the FPSO becomes gas deficient or is shutdown, gas can be imported from the WoSPS system. The produced water will be treated and reinjected into the field with seawater that has been treated to produce low sulphate seawater in the Sulphate Removal Unit (SRU), to provide reservoir pressure support.

The selected FPSO concept is the Altera Infrastructure (AIP) owned Petrojarl Knarr FPSO built 2014, which was operating on the Knarr Field for Shell in the Norwegian Sector of the North Sea. The FPSO will be renamed as part of the redeployment to the Petrojarl Rosebank (hereafter referred to as Rosebank) and be capable of being retained in the field for 25 years. The hull has an oil storage capacity of 800,000 barrels of oil and topsides facility has a design processing capacity of approximately 70,000 barrels of oil per day and 60 MMSCF of gas per day [16]. Ahead of redeployment, the FPSO has undertaken all required modifications ~~significant modification~~ in a shipyard prior to operations on the Rosebank Field to enable the installation to be electrification ready, with no further modifications required once operating in-field to enable power from shore. As a result, Rosebank could become one of the first oil and gas developments west of Shetland to be powered by electricity from shore, reducing the emissions and supporting the North Sea Transition deal supply decarbonisation target of achieving a net-zero basin in the UK by 2050.

The main power supply is obtained by four, dual fuel Solar Titan 130 Turbine Generators, operated in a three out of four (3oo4) configuration with the load shared and preferentially operated on fuel gas. The power generation turbines selected are fitted with Solar's SoLoNOx^{TM} Dry Low-Emission (DLE) combustion technology, which is optimised to reduce emissions by tightly controlling the combustion temperature inside the turbine.

Emissions of oxides of sulphur from the combustion equipment at the installation are a function of the Sulphur content of the fuels burnt. All of the main power generating gas turbines will be preferentially operated on fuel gas (associated gas from the Rosebank field or Import gas for the WoSPS) which is inherently low in sulphur minimising the emissions of SO_2 from combustion equipment. In the event of downtime of the Sulphur Removal Unit (SRU) plant, sea water injection shall be stopped to prevent souring of the production fluids and potential for increased sulphur content of the associated fuel gas. Low Sulphur diesel (< 0.1 wt.%) is also used as a back-up fuel source for gas turbines for infrequent events where enough fuel gas is not available.

To reduce emissions from the installation, a vapour (and flare gas) recovery unit (VRU), which recycles waste streams that would otherwise be routed to flare has been installed. This system recovers volatile organic compounds (VOCs) from multiple sources including crude oil storage, the tri-ethylene glycol system, and the produced water treatment system and recirculates them back into the process.

There are four diesel driven fixed speed electrical firewater pumps (FWPs), two located in the forward section of the vessel and two at the aft. When there is demand, two firewater pumps are required for full FPSO coverage. Upon failure of main power, the diesel engine driven essential and emergency generator will support normal conditions of habitability and essential marine/process systems. ~~There are no routine users of diesel.~~ Diesel is not used routinely except for testing the engines. Testing is carried out on a monthly basis to ensure equipment readiness.

The FPSO also has an inert gas generator (IGG) which supplies safe combustion gases to cargo oil storage tanks to maintain a low-oxygen atmosphere and facilitate maintenance activities. The IGG operates on diesel/gas oil and is expected to operate for around 48 hours [10] per year on average during periods the VRU is unavailable.

Facility heat demand for topside process requirements is primarily recovered from the main power turbine exhaust gas using Waste Heat Recovery Units (WHRUs)). A dual fuel direct fired auxiliary boiler is provided as an alternative source of heat should the WHRUs be unavailable.

Air dispersion modelling has been undertaken to assess the impacts on air quality of emissions from the Rosebank FPSO. The results show that pollutant levels from the FPSO were deemed insignificant and the expected transboundary impacts are likely to be negligible [18].

2.0 LEGISLATIVE BACKGROUND

2.1 Context and Scope

Combustion plant on the Rosebank FPSO must comply with The Offshore Combustion Installations (Pollution Prevention and Control) Regulations 2013, as amended [1]. The Regulations transpose the requirements of both the Industrial Emissions Directive (IED) [2] and the Medium Combustion Plant Directive (MCPD) [4]. The PPC regulations provide separate provisions for the regulation of Large Combustion Installations (LCI) and Medium Combustion Installations (MCI), and the management of Large Combustion Plants (LCP), including provisions under IED Chapter 3 and the LCP BAT Reference (BREF) document). They also cover Medium Combustion Plants (MCP) and other qualifying combustion plants.

The Regulations require LCI to be operated using Best Available Techniques (BAT). An integrated approach to BAT assessment for the whole LCI is required, rather than assessing individual emissions or unit operations in isolation. The BAT assessment should cover all combustion equipment on the LCI such as power generation and compression gas turbines, engines, and boilers.

This ~~report~~ BAT assessment describes the process undertaken to select the Rosebank combustion plant and demonstrates that environmental emissions are mitigated by applying BAT. This process was undertaken during the project concept select phase and used estimated loads at that stage.

The ~~aggregation rules stated within the~~ PPC regulations [1] provide~~s~~ context to when installations are considered an MCI/LCI (based on the aggregation of rated thermal input at the installation level) and when a BAT assessment is required.

Where an LCI is defined as:

- (a) a relevant platform; or
- (b) a complex of relevant platforms permanently inter-connected by bridges,
- equipped with an offshore combustion plant which on its own or aggregated together with any other combustion plant on the same platform or complex has a rated thermal input which is equal to or greater than 50 megawatts;

And an MCI is defined as

- (a) a relevant platform; or
- (b) a complex of relevant platforms permanently inter-connected by bridges,
- which is not a large combustion installation and which is equipped with an offshore combustion plant that has a rated thermal input which is equal to or greater than 1 megawatt and less than 50 megawatts.

~~As~~ The combined thermal input of the installation ~~main~~ combustion plant, including ~~(~~four Gas Turbine Generators (GTG) each with maximum thermal input of 42.106 MW_{th}, one Auxilliary Boiler (9.061MW_{th}), Emergency Generator (6.06MW_{th}) and Essential Generator (5.91MW_{th})~~)~~, plus the combined rated thermal input of the other combustion plant on the permit aggregate to provide a total thermal capacity of the ~~main~~ combustion plant being ~~189.452~~ 213.302 MW_{th}, ~~which exceeds 50 MW_{th}.~~ Due to the combined thermal input of the combustion plant exceeding 50 MW_{th}, the FPSO is considered a Large Combustion Installation (LCI).

As Rosebank is categorised as an LCI installation, a BAT assessment is required and will refer to the best available techniques in accordance with Chapter 10 of the LCP BREF.

Furthermore, the tables in Appendix A present the techniques that have been considered in the determination of BAT for the prevention or reduction of emissions from the combustion of gaseous fuels and for increasing the thermal efficiency, in line with LCP BREF recommendations.

2.2 Best Available Techniques

The Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 2013 (as amended) [1]; hereafter referred to as the PPC Regulations, transpose the relevant provisions of the Industrial Emissions Directive 2010/75/EU (IED) [2] with respect to specific atmospheric pollutants from offshore combustion installations with total thermal capacities exceeding 50 megawatts (MW_{th}). A key element of the IED which is transposed into the PPC Regulations is the concept of BAT.

Best Available Techniques, as defined in the PPC Regulations, are as follows:

"best available techniques" means the most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing the basis for emission limit values (ELVs) and other permit conditions designed to prevent and, where that is not practicable, to reduce emissions and the impact on the environment as a whole.

"available techniques" means those techniques developed on a scale which allows implementation under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced in the United Kingdom, the offshore area or the relevant gas area, as long as they are reasonably accessible to the operator.

"best" means most effective in achieving a high general level of protection of the environment as a whole.

BAT for a given industrial sector are described in BAT reference document (BREF) [14]. BAT conclusions (BATc) contained in the BREFs are given a legal standing and provide the framework for each given sector considered by Competent Authorities when issuing permits.

Demonstration that BAT has been implemented requires a review of combustion operations and an assessment of what measures, if any, could reasonably be implemented to minimise emissions and discharges. As an aid to this process the Department for Energy Security & Net Zero (DESNZ) has published an offshore specific guidance note [5]~~, though it should be noted that this was written against earlier 2001 Regulations~~.

The principal environmental releases associated with the combustion activities offshore are those to the atmosphere. Therefore, the emissions profiles are included under the Environmental Impact Assessment (EIA) Justification of the Production Master Application Template (MAT), and they are critical in assessing the impact of the combustion activities and in demonstration of BAT.

The prescribed pollutants under PPC are emissions of:

- NO_x – Oxides of Nitrogen, and other compounds containing nitrogen
- SO_2 – Sulphur Dioxide, and other compounds containing sulphur
- CO – Carbon Monoxide
- CH_4 – Methane and non-methane Volatile Organic Compounds (nmVOCs); and
- Particulate Matter (PM).

BAT for the offshore sector is usually assessed in terms of assessing the environmental impact of these pollutants, in particular NO_x, in addition to considering the energy performance of main combustion equipment on the installation in line with the offshore guidance [5].

This PPC BAT assessment supports the Pollution Prevention and Control (PPC) Subsidiary Application Template (SAT) submission for the Rosebank FPSO (PPC/~~352~~123) [3] and provides details of the Best Available Techniques (BAT) Assessment undertaken as required under the PPC Regulations.

The Department for Energy Security and Net Zero (DESNZ), formerly the Department of Business Energy and Industrial Strategy (BEIS), has indicated in their guidance [5] that a permit holder should continue to review developments, both in line with the latest published BREF document for the sector, and in line with dynamic assessment of industry / sector best practice and experience. This relates to a combustion installation, that is any offshore platform equipped with combustion plant e.g. turbines, engines or heaters that use fuel, either gaseous or liquid, to generate energy for the operation of the facility. The demonstration of BAT should focus on how the existing equipment is being managed to reduce emissions. Upgrading existing equipment to match the performance of current advanced technology would not be a routine expectation of the PPC permit conditions.

2.3 LCP Equipment Screening Assessment

Large Combustion Plant (LCP) are defined as combustion plant with a total rated thermal input equal to or greater than 50 megawatts (MW_{th}). Article 28(2)(i) of the IED [2] explicitly excludes 'gas turbines and gas engines used on offshore platforms' from Chapter III scope. While Chapter III does not formally apply to the installation's gas turbines, the LCP BREF is nonetheless used as the BAT reference per sections 2 and 3 of the PPC guidance [5].

When assessing each of the combustion plant in turn, the regulations [1] set out aggregation rules which must be taken~~ing~~ into account ~~to identify~~ when assessing any eligible LCP. These rules come from Article 29, Chapter III of the 2010 directive and are as follows.

- Where the waste gases of two or more separate combustion plants are discharged through a common stack, the combination formed by such plants shall be considered as a single combustion plant and their capacities added for the purpose of calculating the total rated thermal input.
- For the purposes of calculating the rated total thermal input of a combination of combustion plants discharged through a common stack, the individual combustion plants with rated thermal input greater than or equal 15MW shall be taken into consideration. Where the rated total thermal input is equal to or greater than 50MW the aggregated combustion plant is LCP covered by chapter III.
- ~~"Combustion of fuels in installations with a total rated thermal input of 50MW or more", this general aggregation rule means that all combustion activities within an installation need to be considered, i.e., there is no threshold at unit level. If the total rated thermal input of all those combustion activities within the installation is 50 MW or more, then the whole installation falls under the scope of Chapter III of the IED.~~

The Rosebank FPSO associated combustion plant list found in Table 4-1 was reviewed to identify any equipment which has a thermal input of or greater than $50MW_{th}$. The largest combustion plant on the Rosebank FPSO are the four Solar Titan 130's power turbines, which have a maximum thermal input at the corresponding International Organisation for Standardisation (ISO) standard reference conditions (i.e. at 15°C, 60% humidity and atmospheric pressure at sea level) of 42.106 MW_{th} as illustrated in ~~Table 2-2~~ Table 2-1 LCP Equipment Assessment.

Table 2-1 LCP Equipment Assessment

COMBUSTION EQUIPMENT	SITE ISO BASELOAD RATED OUTPUT (MW_e)	MAXIMUM THERMAL INPUT (MW_{th})	EXISTING/NEW	LCP CRITERIA MET?	TYPE OF COMBUSTOR (STANDARD / DLE)
4 x Solar Titan 130-20501S	14.055 [1]	42.106 [1]	New	No	DLE (SoLoNO$_x$™)

***Note [1]** Presented turbine rated output and thermal capacity based on predicted Solar Titan 130 engine performance when fuelled by Import gas spec from WoSPS pipeline, stated at ISO standard conditions i.e 15 °C / 60% humidity and 1.013 bara which is standard atmospheric pressure at sea level.*

~~As~~ The installations ~~main~~ combustion equipment does not include any individual combustion equipment which meet the ~~with a rated thermal input greater than~~ 50MW_{th} LCP threshold and no combustion plants are discharged through a common stack whereby the aggregation rules apply ~~therefore~~, the installation does not contain any LCP. As such the BATc from ~~the~~ chapter 10 of LCP BREF do not apply. However as the combined thermal input of the Rosebank combustion plant aggregates to more than 50MW_{th}, it is categorised as an LCI installation. As discussed, while the provisions of Chapter III of the IED [1] do not formally apply to the installation's gas turbines, due to the exclusion conditions covered under Article 28(i), the LCP BREF is used as the BAT reference per sections 2 and 3 of the PPC guidance [5]. This BAT assessment therefore addresses Chapter 10 of the LCP BREF accordingly. ~~and This BAT assessment will refer to the best available techniques in accordance with Chapter 10 of the LCP BREF.~~

2.4 Medium Combustion Plant

Regulation 2A [1] states that MCP is classed as an offshore combustion plant which has ~~Equipment that is classified as MCP, has~~ a rated thermal input of equal or greater than 1MW_{th} but below 50MW_{th}. This includes boilers, direct fired heaters and dual fuel engines. Gas turbines, gas engines and diesel engines are exempt, as are combustion plant in which gaseous products of combustion are used for the direct heating, drying, or any other treatment of objects or materials.

In accordance with the MCPD [4], permit conditions are set to minimise discharges, emissions, and waste of MCP through the application of BAT. This includes the setting of binding Emissions Limit Values (ELVs) as of the 1st January 2025, which are defined within the MCPD [4] and set in permit conditions based upon BAT.

The Rosebank FPSO associated combustion plant list found in Table 4-1 was reviewed to identify any equipment which meet the definition of MCP. ~~Therefore, in accordance with the MCPD,~~ The Aalborg Auxiliary boiler onboard the Rosebank FPSO is classified as MCP and must ~~1) minimise discharges, emissions, and waste through the application of BAT and 2)~~ adhere to the ELVs set out in Part 1 of Annex II.

The GTGs installed on the Rosebank FPSO are not classified as MCP ~~However, the individual thermal rating of each turbine is less than 50MW$_{th}$ and due to the gas turbines being situated offshore, they are not classed as MCP. Therefore,~~ and there are no statutory emissions limits that are applicable for these turbines, however, the Regulator may set emission limit values as a condition in the PPC permit.

2.4.1 New and Existing Plant Definition

For the purposes of determining compliance with the relevant ELVs contained within Annex II of the MCPD [4], it is important to correctly categorise the combustion plant on the installation according to the definitions of 'new' and 'existing' plant. Extracted from the definitions section of the MCPD, 'new' and 'existing' plant are as follows:

- 'Existing combustion plant' means a combustion plant put into operation before 20th December 2018 or for which a permit was granted before 19 December 2017 pursuant to national legislation provided that the plant is put into operation no later than 20th December 2018"; and
- 'New combustion plant' means a combustion plant other than an existing combustion plant".

Following the definitions above, despite the FPSO having previously been deployed, the MCP onboard the installation can be considered "new" combustion plant and must therefore adhere to the ELVs set out in Part ~~1~~ 2 of Annex II [9].

2.4.2 ~~Associated Emissions Levels~~ Emission Limit Values

Operators of ~~MCP~~ installations with MCP must carry out monitoring of emissions to demonstrate compliance with the ELVs within four months of a permit being granted (it is proposed to carry out associated stack monitoring within four months of the start of normal operations (SONO) to derived representative results), and then at the following frequency:

- Every three years for MCP with a rated thermal input equal to or greater than 1 MW_{th} and less than or equal to 20 MW_{th};
- Every year for MCP with a rated thermal input greater than 20 MW_{th}.

SO_2, NO_x and particulate matter must be monitored. MCP which operates less than 500 hours per year may be exempt from compliance with the ELVs set out below, if this can be demonstrated as a rolling average over a period of ~~five~~ three years, in accordance with regulation 11D.

As the primary source of facility heat is derived from the WHRUs, it is expected the Auxiliary boiler will be operated well below the threshold (<500 hours online per annum) whereby the ELVs apply. However, for ease of reference the relevant ELVs (expressed in mg/Nm^3) from Part ~~1~~ 2 of Annex II of the MCPD are replicated in Table 2-2.

The MCPD provides ELV's for oxides of nitrogen (NO_x) and sulphur dioxide (SO_2) for gaseous fuels, with distinct limits for both 'natural gas' and 'gaseous fuels other than natural gas'. 'Natural gas' is defined within the MCPD as gas containing naturally occurring methane with no more than 20 % (by volume) of inerts and other constituents.

The expected gas composition of both WoSPS import gas (see Section 5.2) and predicted early field life Rosebank associated gas indicate methane concentration of ~87%, which meets the definition of 'natural gas' under MCPD and the applicable ELV's are shown in Table 2-2 below.

Table 2-2 MCP Emission Limit Values (ELV's)

ELV's (mg/Nm3) for new medium combustion plants other than engines and gas turbines		
Pollutant	**Gas Oil**	**~~Gaseous fuels other than natural gas~~ Natural Gas**
SO_2	-	~~35 (1) (2)~~
NO_X	200	~~200~~ 100
Dust	-	-

~~(1) 400 mg/Nm3 in the case of low calorific gases from coke ovens, and 200 mg/Nm3 in the case of low calorific gases from blast furnaces, in the iron and steel industry.~~

~~(2) 100 mg/Nm3 in the case of biogas.~~

The Aalborg Auxiliary boiler is classified as MCP and has yet to be operated, therefore will be categorised as new combustion plant. As such the NO_x ELV of ~~2~~100 mg/Nm^3 will apply. However, as it is expected to be operated less than 500 hours per annum, the exemption threshold applies and Altera will provide a signed declaration that the MCP will not operate more than the permitted hours as part of the PPC permit submission.

3.0 TURBINE ASSESSMENT METHODOLOGY

During the final concept select phase of the project, studies were undertaken to determine the power requirements for the Rosebank FPSO process, utility and accommodation systems [11] in coordination with the final floating facilities selection process [6]. In order to balance emissions, efficiency, availability, reliability, and capital cost and as such, represent the Best Available Technique (BAT) to provide the Rosebank FPSO with power the following turbines were required:

- Gas Turbine Generators (GTGs) for the main power supply to the Rosebank FPSO (4 x 50% configuration [1])

Note [1] – Original concept select turbine selection criteria was arrangement of main power generators in a 4 x 50% configuration based on the average predicted project power demand outlined in Rosebank Environmental Statement [6]. The original load demand differs from the predicted maximum estimated normal load demand [9] based on the latest project information available, which results in the installed turbine capacity equating to a 4 x 33% configuration.

Consideration of the following criteria were evaluated during the facilities selection process [6]:

- Technical feasibility – suitability for offshore deployment, approved, has references.
- Ability to meet load (and heat) demand
- Energy Efficiency – thermal efficiency across the load range (including part load).
- NO_x emissions to air when operating in DLE mode of <25 ppm – <DLE 25 ppm.
- Fuel Quality, and
- Cost – lowest cost.

To mitigate the high cost and environmental impact associated with building a new FPSO, redeployment of the Altera owned Knarr FPSO was selected as the concept for the Rosebank development due to it being considered equivalent to a new build in terms of an operations emissions perspective. The existence of closed flare and vent systems already in operation on the FPSO, and suitability for future electrification with available space allocated in the turret and it allowing for phased drilling and wells, improving reservoir management.

Furthermore, all power turbines installed on the FPSO were fitted with state-of-the art DLE control systems to reduce environmental discharges of NOx, CO, and unburned hydrocarbons. Together with waste heat recovery packages which utilise the hot exhaust gases to meet the heat duty requirements of process equipment, the equipment configuration balanced emissions, efficiency, availability and reliability and as such, represented the Best Available Technique (BAT) to provide the Rosebank FPSO with power.

Redeployment of the FPSO was also considered the most economically viable option, as well as significantly reducing GHG emissions compared to fabrication and transport of a new build.

3.1 Main Power Supply

The Solar Titan 130 fitted on the FPSO as part of the main power generation package are installed in a 4 x 3350% configuration to meet the maximum estimated normal electrical demand requirements. All turbines are fitted with Solar's SoLoNO$_x$™ Dry Low-Emissions combustion technology which is optimised to reduce emissions by tightly controlling the combustion temperature inside the turbine. Normal operating philosophy is to operate in a three out of four (3oo4) configuration with load shared. The fourth machine will be on cold standby, and no spinning reserve maintained. Running hours will be shared across all machines, therefore, there may be rare occasions when all four machines run together for short durations such as during turbine switch-over operations. Combustion gases are discharged to the local environment via a stand-alone (one per gas turbine) exhaust/discharge stack to ensure all components are dispersed and to enable maintenance of individual turbines without the requirement for a full facility-wide shutdown. Ports are available in the exhaust stacks to enable sampling of effluent gases with a traversing probe.

4.0 COMBUSTION PLANT

The aggregated thermal input of the combustion plant on the Rosebank FPSO classes it as a Large Combustion Installation (LCI). None of the individual combustion plant on the FPSO meet the classification criteria of Large Combustion plant (LCP), however, the Auxiliary boiler is classified as Medium Combustion Plant (MCP). A list of the combustion plant on the Rosebank FPSO is provided in Table 4-1 below.

Table 4-1 Combustion Plant on Rosebank FPSO

EQUIPMENT NAME	TAG NUMBER	FUEL TYPE	MAX RATED OUTPUT (MW)	MAXIMUM THERMAL INPUT (MW_{TH})	RATED THERMAL EFFICIENCY %	EXPECTED RUNNING HOURS (~~2026 FORECAST~~ 2027 FORECAST – NORMAL OPERATION)	MCP	LCP
Solar Titan 130	80-DE-001A	Dual	14.055 [1]	42.106	33.380[1]	5950	NO	NO
Solar Titan 130	80-DE-001B	Dual	14.055 [1]	42.106	33.380 [1]	5950	NO	NO
Solar Titan 130	80-DE-001C	Dual	14.055 [1]	42.106	33.380 [1]	5950	NO	NO
Solar Titan 130	80-DE-001D	Dual	14.055 [1]	42.106	33.380 [1]	5950	NO	NO
ESDG MAN STX Engine	80-DD-501	Diesel	2.45	5.910	41.5	48	NO	NO
EMGEN MTU 20V4000P63	84-DD-501	Diesel	2.6	6.057	42.9	48	NO	NO
Auxiliary Boiler AALBORGOL 39280	55-FB-501	Dual	8.0	9.061	88.3	96	YES	NO
Inert Gas Generator Hamworthy MOSS AS	64-VV-501	Diesel	0.11	4.978	2.2	48	NO	NO
Cummins QSK60 Diesel Fire Pump 1	71-DD-553	Diesel	1.9	4.718	40.3	12	NO	NO
Cummins QSK60 Diesel Fire Pump 2	71-DD-558	Diesel	1.9	4.718	40.3	12	NO	NO
Cummins QSK60 Diesel Fire Pump 3	71-DD-564	Diesel	1.9	4.718	40.3	12	NO	NO
Cummins QSK60 Diesel Fire Pump 4	71-DD-571	Diesel	1.9	4.718	40.3	12	NO	NO
Total			78.98	213.302				

Note [1] Inputs and efficiencies are based on OEM turbine performance data supplied for the GTG's at ISO standard conditions i.e 15 ˚C / 60% humidity and 1.013 bara which is standard atmospheric pressure at sea level[13].

Note [2] Running hours based on the forecast for 2027 and subsequent years assuming full uptime with main power turbines in 3oo4 configuration (normal operation) [10].

4.1 Main Power Generation

The maximum estimated normal electrical demand for the Rosebank FPSO is around 28.978 MW_e during production operations. The estimated electrical load demand has increased from the original installation requirements outlined in the Environmental Statement [6], primarily due to the estimated load being based on the maximum possible load demand i.e. inclusive of ancillary equipment such as chemical injection pumps which will see intermittent service under normal operations.

Consistent with the original Environmental statement [6], the operating philosophy is to run in a 3oo4 turbine configuration for the first 17 years of field life reducing to two later in field life. Whilst two GTG's may be capable of supplying the maximum estimated load (based on all process related equipment being online), a three turbine configuration is preferential in early production to mitigate process trips associated with a loss of primary power generation (due to no spinning reserve being maintained on dispatchable spare turbines). It is expected that as the installation achieves stable production, where possible an N+1 configuration will be adopted, where N equals two online turbines supplying the power output requirement with a third dispatchable turbine supplementing if demand is too high. This is a common design concept which allows for maintenance and overhaul with no loss of generation capacity.

Peak power demand will occur during offloading operations and is estimated to reach 31.709 MW_e [9]. Offloading operations are expected to be carried out every 8-9 days in early production and will take approximately one day.

Offloading is expected to be carried out at the aforementioned frequency for the duration of the production plateau period which is expected extend through until 2033 (Drilling is carried out over two phases and extends this period), when production is expected to decline. The frequency of offloads will thereafter be proportionate to the production rate.

Installation load is expected to remain steady in future years during normal production and offloading operations. The largest consumers of power on the FPSO are illustrated in Table 4-2 and Figure 4-1 as follows [9]:

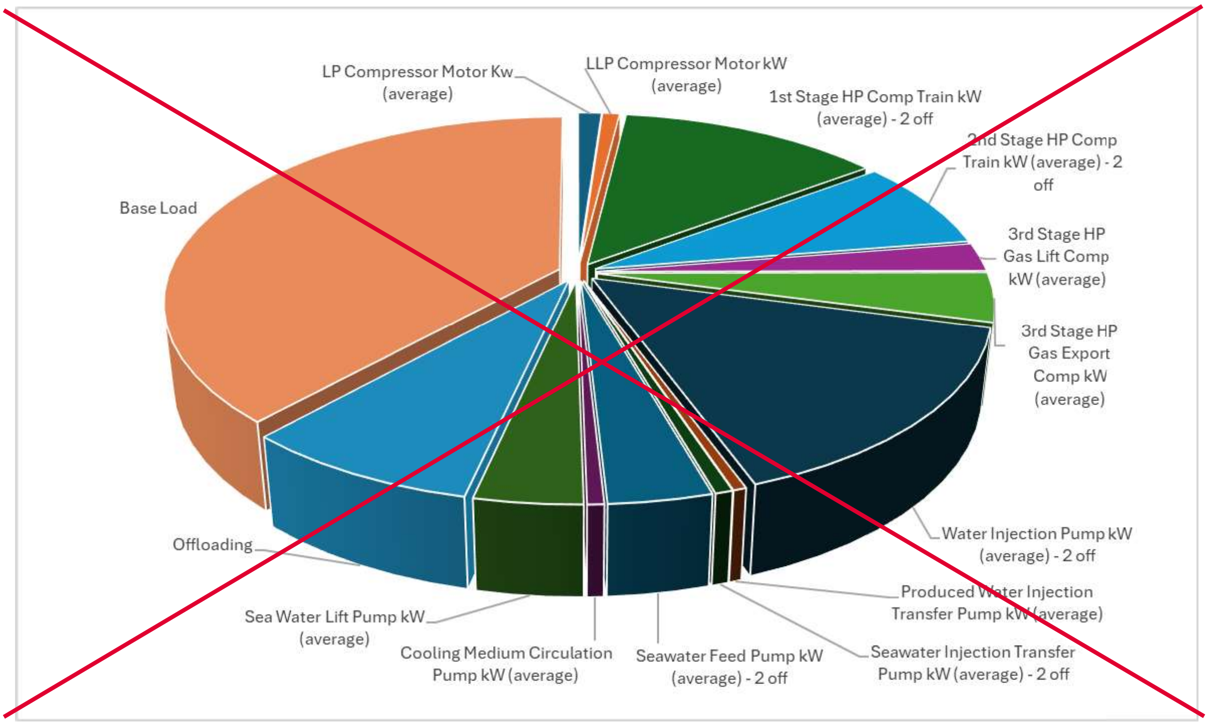
Table 4-2 Main Electrical Consumers on Rosebank FPSO

~~EQUIPMENT DESCRIPTION~~	~~TOTAL NORMAL OPERATIONS PROCESS DEMAND (KW) [9]~~
~~Installation Base Load~~	~~11180~~
~~Water Injection Pump kW (average) 2oo3~~	~~5094.8~~
~~1st Stage HP Comp Train kW (average) 2oo2~~	~~4254~~
~~Offloading (Offload Pumps and ancillary systems)~~	~~2731~~
~~2nd Stage HP Comp Train kW (average) - 2oo2~~	~~2579.2~~
~~3rd Stage HP Gas Export Comp kW (average)~~	~~1420.4~~
~~Sea Water Lift Pump kW (average)~~	~~1239.7~~
~~Seawater Feed Pump kW (average) - 2oo2~~	~~1191.2~~
~~3rd Stage HP Gas Lift Comp kW (average)~~	~~818.9~~
~~LP Compressor Motor Kw (average)~~	~~373.5~~
~~LLP Compressor Motor kW (average)~~	~~277~~
~~Seawater Injection Transfer Pump kW (average) - 2oo2~~	~~204.2~~
~~Cooling Medium Circulation Pump kW (average)~~	~~192~~
~~Produced Water Injection Transfer Pump kW (average)~~	~~153.1~~

-	-
~~**Total Load Demand Normal Operations [9]**~~	~~**28978 [1]**~~
~~**Peak Load Demand Normal Operations Plus Offload [9]**~~	~~**31709**~~
~~**Offloading (Offload Pumps and ancillary systems)**~~	~~2731~~

Note [1] *Loads presented are based on forecasted load in event all operational equipment is online i.e. inclusive of chemical injection pumps which will see intermittent service under normal operations. Once sufficient data is available during steady state operations the table presented will be reviewed and amended accordingly.*

EQUIPMENT DESCRIPTION	TOTAL NORMAL OPERATIONS PROCESS DEMAND (KW) [9]
Base Load	8062.5
Water Injection Pump kW (average) - 2 off	5094.8
1st Stage HP Comp Train kW (average) - 2 off	4254
Ancillary Process Equipment (i.e. chemical injection pumps)	3117.5
2nd Stage HP Comp Train kW (average) - 2 off	2579.2
3rd Stage HP Gas Export Comp kW (average)	1420.4
Sea Water Lift Pump kW (average)	1239.7
Seawater Feed Pump kW (average) - 2 off	1191.2
3rd Stage HP Gas Lift Comp kW (average)	818.9
LP Compressor Motor Kw (average)	373.5
LLP Compressor Motor kW (average)	277
Seawater Injection Transfer Pump kW (average) - 2 off	204.2
Cooling Medium Circulation Pump kW (average)	192
Produced Water Injection Transfer Pump kW (average)	153.1
Total Load Demand Normal Operations [9]	**28978 [1]**
Peak Load Demand Normal Operations Plus Offload [9]	**31709**
Offloading (Offload Pumps and ancillary systems)	2731



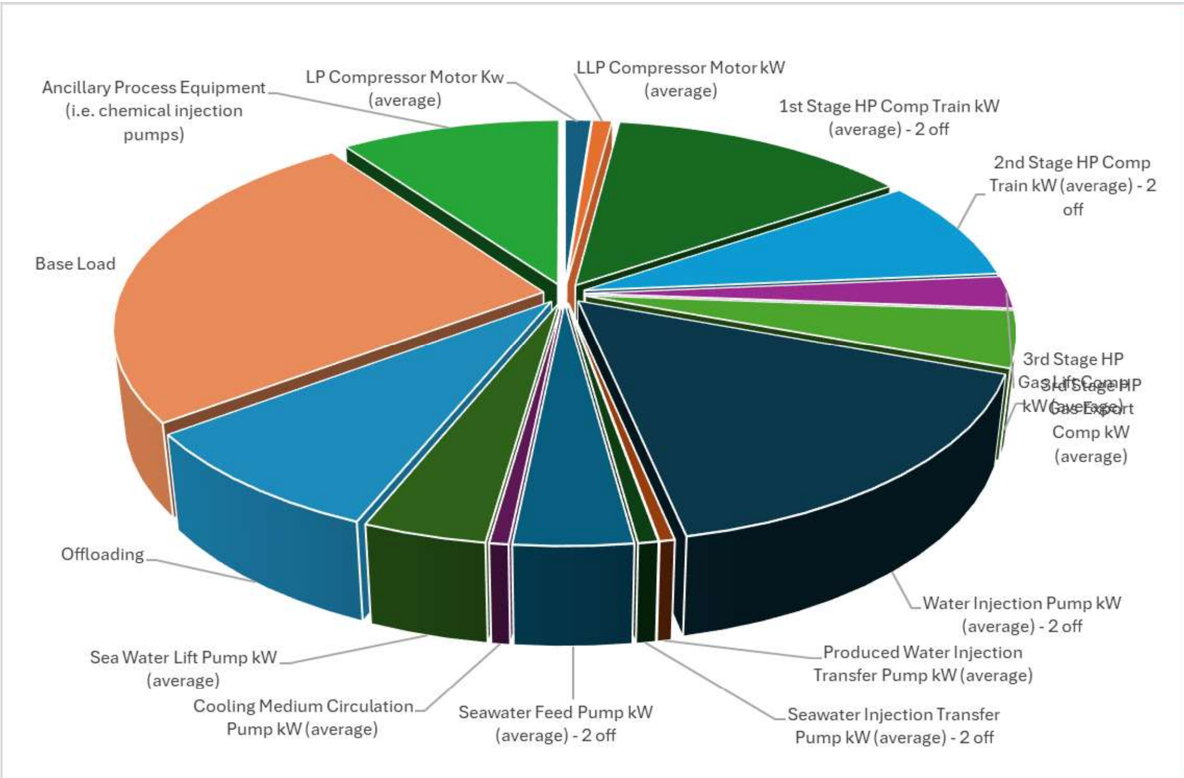


Figure 4-1 Estimated Electrical Load requirement for the Rosebank FPSO

A breakdown of the main switchboard consumers comprising the "Installation base load" category in Figure 4-1 is shown below in Table 4-3.

Table 4-3 Installation Base Load Consumers on Rosebank FPSO

EQUIPMENT DESCRIPTION	TOTAL NORMAL OPERATIONS PROCESS DEMAND (KW) [9]	EXPECTED BASE LOAD – NON-PRODUCTION (KW)
E-house 60kV Switchboard	0	0
E-house 11kV Switchboard	0	0
11kV Main High Voltage Switchboard	420.0	0
11kV Hull High Voltage Switchboard	4300	2138
690V Topside Main Process Switchboard	96.8	0
690V Hull Switchboard AFT	698.6	582
690V Hull Switchboard FWD	998.0	693
690V Topside Essential SWG	150.9	147
690V Hull Main Emergency Switchboard	496	339
690V Turret Switchboard	95.8	0
Cargo Pump Switchboard	806.3	0
Total	**8062.5**	**3900**

The electrical power will be provided by the four Solar Titan 130 Turbines which each have a maximum power output of 14.372MW at the expected average annual site ambient temperature of 10˚C. Fuel gas is preferentially used as the main fuel supply; however, the turbines are capable of dual fuel operation (i.e., fuel gas and diesel). There is the potential to import gas from West of Shetland Pipeline System (WoSPS) if the field becomes depleted of gas and it is still required for power generation, although this is a contingency [2].

The power turbines employ Dry Low Emissions (DLE) technology (SoLoNO$_x$™ nozzles) to reduce NO_x generation from the turbines. The basic principle of operation in the DLE technology is close control of the flame temperature to reduce NOx emissions to as low as 25 ppmv (measured on dry off gas, 15% O_2). The DLE technology does not require additional chemicals or energy, compared to a turbine without a low NO_x solution. By incorporating lean pre-mix combustors in the turbine, DLE systems allow for reduced NO_x emissions without the use of steam or water suppressors, and without increasing CO emissions. DLE provides the best environmental performance compared to other techniques, so is considered BAT.

4.1.1 Load Shedding & Strategy

To ensure supply is maintained where possible, load shedding shall be executed in the following levels:

- The first level, to be implemented following detection of an under-frequency condition, shall consist of step by step (if required) shedding of consumers according to a pre-set priority, which shall continue until the frequency returns to normal state; and
- The second level of load shedding, to be implemented following the loss (i.e. tripping) of an operating GTG (or tripping of HV switchboard bus tie breaker) shall consist of a general shedding of load blocks. The amount of load to be shed shall depend on the power which was previously provided by the source which was lost and the capability of the remaining turbines (if required).

4.1.2 Operating Philosophy

The maximum estimated power requirement of the Rosebank FPSO whilst offloading (31.709 MW_e) will require three out of four (3oo4) power turbines to be running. The main intent of the operating philosophy is to minimise power usage whilst reducing the need for spinning reserve. The estimated load during both normal production and production plus offloading, will allow power generation to be supplied from three turbines [10]. The fourth turbine is only used as a backup for maintenance and will not be operated under normal operations. The operating load point of online turbines at around 70% loading each, maximising the advantage of the SoloNO$_x$™ technology, which is enabled at loads higher than 51%, reducing overall emissions from the power generation package.

During extended periods of production outages e.g. gas compressor outages or planned shutdowns, the operating philosophy will be to load a single GTG preferentially fueled by imported fuel gas from the WoSPS pipeline. In this scenario, the GTG will operate around 28% of it's maximum rated output (based on the expected base load during non-production operations of 3.9 MW_e), which falls below the DLE activation threshold noted above.

During scenarios such as plant start-up and recovery, the offshore production team will follow established and approved operating procedures to ensure that systems are brought back into service safely, reliably and as efficiently as possible, minimizing time spent in other than normal operating conditions (OTNOC). The operational philosophy is to avoid OTNOC where practicable and, where they do occur, to minimise both their frequency and duration, recognising that extended recovery periods can result in increased emissions and operational inefficiencies. Key process parameters will be monitored throughout the recovery phase to ensure a controlled return to normal operating conditions. Delays in recovery activities will be avoided where practicable, as prolonged start-up phases can lead to extended periods of operation below the DLE activation threshold.

4.1.3 Hook-up and Commissioning Activities

A commissioning period will be undertaken (estimated to be around 7 months in duration inclusive of the operations discussed further in this section), following arrival of the Rosebank FPSO on station. Prior to entry into United Kingdom territorial waters, all GTGs will have been commissioned on diesel to ensure equipment readiness.

The FPSO will be installed with twelve mooring lines positioned in three groups of four suction anchors and anchor chains. Once the FPSO is towed into the field, the pre-laid risers and umbilical's as described in the Rosebank Environmental Statement [6] will be hooked-up (estimated to be undertaken across a two month window subject to weather) ahead of a riser leak test, expected to be completed approximately one week after riser and umbilical pull-in.

Upon arrival on station, the FPSO will operate in the following power generation modes in support of hook-up and commissioning activities until SONO is achieved:

- One GTG running on diesel at approximately 28% load will provide sufficient power to meet the installation's base load requirements (See Table 4-3). This operating mode will remain in place until the import of WoSPS gas is established (operation mode expected to last approximately 4 months). Import of fuel gas via WoSPS will only commence following completion of dewatering and commissioning activities.
- Following the availability of fuel gas, all GTGs will be commissioned on fuel gas, including the activation of auto-switch capability between fuel sources (~3 weeks duration).

- Compressor commissioning activities will be undertaken using two GTGs operating on fuel gas at approximately 75% load (~2.5 months) until establishment of gas export.
- Once gas export operations commence (This signifies the start of normal operations (SONO)) planned for mid to late-November 2026, three GTGs will operate on fuel gas at approximately 70% load to support full operational requirements.

4.1.4 Waste Heat Recovery

Waste heat recovery involves utilising the heat from turbine flue gas for heating purposes which would otherwise be lost to atmosphere, thereby increasing the overall efficiency of combustion equipment.

The WHRUs installed on the Solar Titan main power generation GTGs provide the installations primary source of heat and satisfy the process heat demand under normal operations expected to be ~25.953 MW_{th} for heating crude oil and process equipment. Each WHRU has the capacity to recover a duty of 14.3MW_{th} between 70% and 100% GTG loading. As the peak heating requirements are anticipated to be 25.953 MW_{th} [11], three turbines will be sufficient to provide the total heat demand for the FPSO.

~~To ensure supply is maintained where possible, load shedding shall be executed in the following levels:~~

- ~~The first level, to be implemented following detection of an under-frequency condition, shall consist of step by step (if required) shedding of consumers according to a pre-set priority, which shall continue until the frequency returns to normal state; and~~
- ~~The second level of load shedding, to be implemented following the loss (i.e. tripping) of an operating GTG (or tripping of HV switchboard bus tie breaker) shall consist of a general shedding of load blocks. The amount of load to be shed shall depend on the power which was previously provided by the source which was lost and the capability of the remaining turbines (if required).~~

4.2 Reciprocating Diesel Engines

Given that reciprocating diesel engines are only expected to operate in an emergency, the main considerations when selecting drivers for the firewater pumps, essential and emergency generator were:

- Independence from process systems
- Short start-up sequence
- Stand-alone functionality

Diesel engines provide an efficient and field-proven solution for these applications. Each item of equipment is provided with dedicated fuel storage housed in a skid-mounted day-tank, starting system and engine management controls. Furthermore, each engine has a dedicated, stand-alone discharge/exhaust stack.

4.2.1 Emergency Generator (EMGEN)

The emergency power generator (EMGEN), which is also suitable for black start operations, is supplied by an MTU 20V 4000 P63 Diesel engine (2.6MW), a robust 4-stroke industrial diesel engine which delivers reliable power, low emissions and fast response to load changes.

The emergency generator operates at standstill on automatic standby and shall be automatically initiated by a loss of power to the emergency switchboard. Upon failure of main power, the diesel driven emergency generator provides power supply to equipment deemed critical for life support on the installation and supports normal conditions of habitability and essential marine/process systems. The emergency generator be operated only upon failure of main power generation package or during test runs to ensure it's availability during emergency scenarios conducted for an hour on a monthly basis.

4.2.2 Essential Diesel Generator (ESDG)

In the event of black starts, the essential diesel generator (2.45MW) provides essential power to support the normal conditions of habitability and essential marine/process systems. For topsides, this includes the start-up loads for a turbine generator and some essential process and utility loads. The engine supplying the ESDG will also be test ran on a monthly basis as per above, otherwise the engine is offline.

4.2.3 Fire Water Pumps (FWPs)

There are four diesel driven fire water pumps (FWPs), two located in the forward section of the vessel and two in the aft which run at 100% load when used. The engines are 4 x Cummins QSK60 Diesel engines which power an electric pump at a maximum power of 2547hp at 1800rpm. When there is demand, two firewater pumps are sufficient for full FPSO coverage. As emergency equipment, the pumps will be tested for around an hour per month to ensure readiness in the event they are required for service.

4.2.4 Inert Gas Generator (IGG)

On the Rosebank FPSO, cargo tank pressure control is normally achieved using hydrocarbon fuel gas sourced from the first stage suction scrubber for A and B compressors. This is used as the primary means of supplying hydrocarbon blanketing gas for oil storage tanks, however, in the event of package or plant shutdown/blowdown, the Inert Gas Generator (IGG) provides a large quantity of safe, inert gas to maintain positive pressure in cargo storage tanks during offloading operations or in preparation for maintenance activities. Diesel fuel is combusted with atmospheric air in a combustion chamber to generate inert combustion gases that contain low concentrations of oxygen. Inert gas is scrubbed and cooled by direct contact with seawater before transfer to the cargo tanks.

The inert gas generator is not expected to run normally and provides a back-up for blanketing gas when the primary means of maintaining positive pressure in cargo storage tanks is not available. It will also be tested for an hour each month to ensure it can continue provide a safe inert gas back-up supply when required. The inert gas generator can also be used to displace hydrocarbon gas from cargo tanks prior to maintenance. Any combustion gases from the inert gas generator are ultimately discharged to the environment via the cargo tank vent stack in the event the VRU is not operational. Combustion gases are diverted to a blow-off line in the package during start-up and through a vent line between the inert gas generator and deck seal during a shutdown.

4.2.5 Auxiliary Boiler

Facility heat demand for topside process requirements is primarily recovered from the main power turbine exhaust gas using waste heat recovery units (WHRUs)). A dual fuel direct fired Aalborg auxiliary boiler is provided as an alternative back-up source of heat for cargo storage tanks and should the WHRUs be unavailable. As per the equipment above, it will be tested monthly to ensure it’s availability in an emergency.

5.0 ENVIRONMENTAL EMISSIONS AND CONTROL

Combustion gases discharged to the environment are the main source of pollution from combustion plant. Combustion gases typically contain oxides of nitrogen (NO_x), oxides of sulphur (SO_x), carbon monoxide (CO) and unburned hydrocarbons (UHCs).

The main mitigation against the production of SO_x from combustion activities is to limit the concentration of sulphur within the fuel. The gas that the combustion engines will run on is produced reservoir hydrocarbon gas. The Rosebank reservoir is not sour and expected to contain only low amounts of sulphur. To mitigate the production of SO_x when running on liquid fuel, the Rosebank FPSO will exclusively run all liquid fuelled combustion equipment on low sulphur diesel (0.1%).

Levels of NO_x, CO and UHCs discharged to the atmosphere are best mitigated in the design and selection of the combustion equipment. To reduce the production of NO_x and CO/UHC, the GTG's have all been installed with the inclusion of Solar's SoLoNO$_X^{TM}$ technology which optimizes the performance of the combustion and fuel systems within the package to reduce NO_x, CO and UHCs at high loads without jeopardising stability or transient capabilities. To maximise the advantage of the SoLoNO$_x$™ technology, the operating philosophy is to operate 3oo4 GTGs at higher loads (greater than 60%) with the fourth turbine offline. This approach is expected to mitigate the CO and NO_x concentrations that can increase at low turbine loads, i.e. when SoLoNO$_x^{TM}$ controls are not active.

Fuel consumed on the Rosebank FPSO is metered using instrumentation that is managed and maintained to meet the strict requirements of The Greenhouse Gas Emissions (GHG) Order, as amended [17]. Where required, fuels are also sampled so that composition can be monitored in line with the requirements of the ~~GHG~~ Greenhouse Gas Emissions Trading Scheme Order 2020 [17]. Fuel gas is also treated prior to combustion in order to meet Solar's fuel gas specification (ES-98).

Emissions arising during other than normal operating conditions (OTNOC), such as FPSO start-up, planned and unplanned outages, etc. have been mitigated by plant design. For example, diesel use in the GTGs is limited to periods when import gas is unavailable. Impacts of such non-standard operations have been incorporated within the emission load calculation [10] prepared as part of the PPC permit submission, using the information provided in Solar Product Information Letters (PIL). This includes estimates for pollutant emissions of NOx, CO, and unburnt hydrocarbons during turbine restarts outlined in PIL 170. OTNOCs typically result in process gas being routed to the flare systems. Flare volumes are monitored and managed in line with the requirements of the installations flare consent.

5.1 Predictive Emissions Monitoring Systems (PEMS)

PEMS are computer-based systems that are used to determine the emissions concentration of a pollutant based on its relationship with a number of characteristics, continuously monitored process parameters (such as fuel gas consumption, air to fuel ratio, combustion temperature, etc.) and fuel or feed quality data of an emission source. Whilst there are no mandatory regulatory drivers for PEMS, such systems do offer supplementary and complementary data that aid compliance with emissions-related regulations [7]. Whilst the Rosebank FPSO previously had functioning Predictive Emission Monitoring System during service across the Knarr field, providing visibility both on and offshore to the DLE Gas Turbine exhaust emissions of NO_x and CO_2, the system has been inactive for many years and will require a full revalidation to ensure veracity of the information provided. Therefore, PEMS is not proposed to be implemented when the FPSO arrives on station. It is however, proposed to assess the quality of data from the existing system during the first year of normal operation following onsite commissioning of the GTGs and any OEM tuning of the DLE system. This will support future introduction of PEMS once a baseline is established and data is recorded to establish daily/monthly DLE operation and emission loads to a satisfactory confidence level.

5.2 Fuel Gas

Hydrocarbon gas produced from the Rosebank wells will be treated in the FPSO topsides systems to provide de-hydrated and super-heated fuel gas to the installed combustion and utility systems:

- Primary fuel supply to GTGs;
- Blanketing gas for cargo tanks during offloading;
- Back-up purge gas for flare systems;
- Seal gas for LLP compressor dry-gas seals during start-up or pressurized shutdown (with partial blowdown); and
- Stripping gas for CFU package and glycol regeneration system.

Produced gas will be dehydrated to 35 ppmV (as per water content specification in WoSPS) and treated for H_2S or mercury if required. Should H_2S arise, the gas will be processed to the WoSPS entry specification of 2.3 ppm of H_2S [6]. Mercury removal will be via a fixed-bed absorbent. The gas will be used as fuel gas on the FPSO, for gas lift in the wells to aid production or exportation to shore via the WoSPS pipeline system. Excess gas from the storage tanks will be handled by the VOC flare recovery system.

Fuel gas composition is expected to be stable, but some changes can be expected during life of the development. Import gas from WoSPS shall be used for power generation during the commissioning phase. Table 5-1 presents the anticipated composition of WoSPS import gas.

Table 5-1 Rosebank Expected Fuel Gas Composition

COMPONENT	WOSPS IMPORT GAS COMPOSITION (MOLE%)
Methane	86.72
Ethane	6.52
Propane	3.56
i-Butane	0.65
n-Butane	1.2
i-Pentane	0.32
n-Pentane	0.36
C6*	0.2
C7*	0.05
C8*	0.01
C9*	0.00
Nitrogen	0.41
Water Vapour	0.00
Hydrogen Sulphide	0.00

5.3 Diesel

Low sulphur diesel conforming to DMA ISO 8217, with a maximum sulphur concentration of 0.1% will be transferred from supply boats to the FPSO [6]. It will be permanently stored in tanks for distribution and consumption when required. Diesel fuel will be used to supply the auxiliary boiler and equipment that is not intended to run on a continuous basis, such as:

- Emergency Power Generator (EMGEN) (84-DD-501
- Direct Drive Engines on all four Fire water pumps
    - FWD Fire Pump A (71-PA-551) engine 71-DD-553
    - FWD Fire Pump B (71-PA-554) engine 71-DD-558
    - AFT Fire Pump A (71-PA-557) engine 71-DD-564
    - AFT Fire Pump B (71-PA-562) engine 71-DD-571
- Essential Standby Diesel Generator MAN STX (ESDG) (80-DD-501)
- Inert Gas Generator (IGG) (64-VV-501)

Diesel fuel is also used as a back-up fuel source for the dual fuel GTGs, during infrequent events where sufficient fuel gas is not available e.g., during start-up or shutdown. During such events, diesel use is recorded using sub-level metering installed on the liquid fuel line to each power generation turbine. Diesel is also supplied to life-boat stations for re-fuelling. All diesel supply to the FPSO and consumption by combustion plant (i.e., GTGs), is accurately metered.

5.4 Turbines

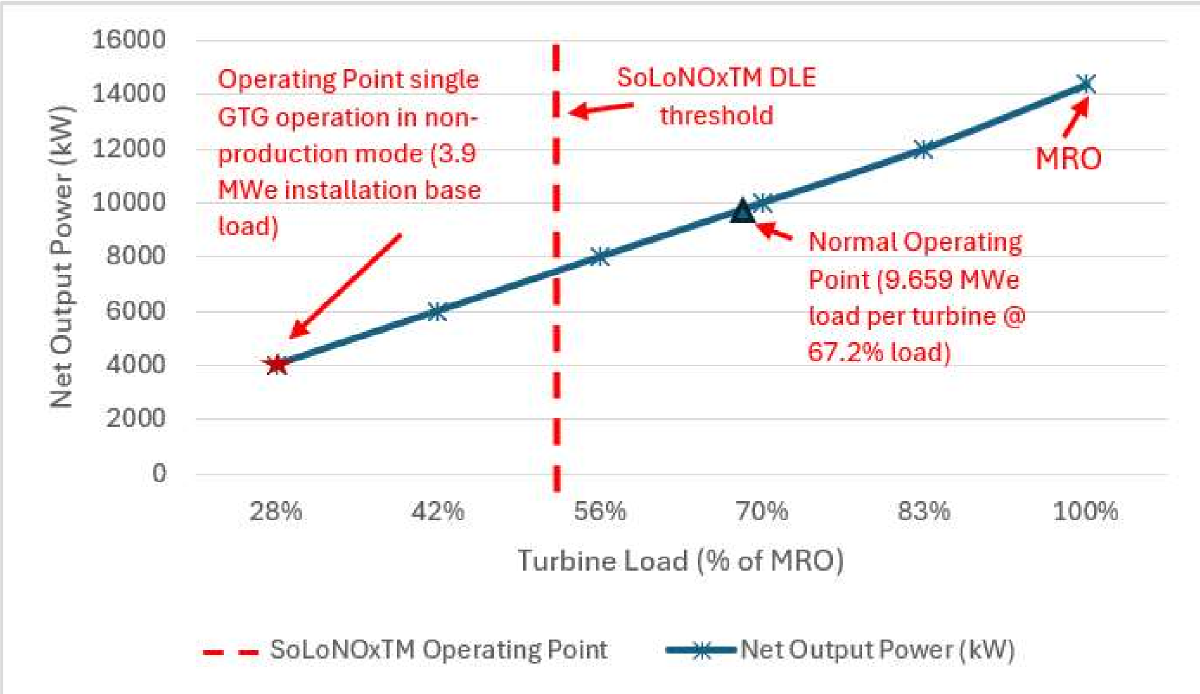
There are four aero derivative single cycle system turbines from Solar Turbines installed on the FPSO. The model of each is Solar Titan 130-20501S. The turbines have DLE technology (SoLoNO$_x$™ nozzles), which is enabled when operated at loads >50% of Maximum Rated Output (MRO), ensuring 25 ppmv of NO_X emissions (measured on dry off gas, 15% O_2) in discharge gases. DLE technology does not require additional chemicals or energy, compared to a turbine without a low NO_x solution. Solar's SoLoNO$_x$™ DLE combustion system tightly controls the combustion conditions in the turbine by fine adjustment of fuel supply and use of fuel pre-mixing and combustion cooling with excess air. The controls are optimised to reduce the formation of CO (which occurs at low combustion temperature) and NO_x (which occurs at high combustion temperature).

During normal operations, the turbines will be operated at around 70% load of MRO (Figure 5-1), ensuring that SoLoNO$_x$™ DLE mode is enabled. However, there will be infrequent periods OTNOC when the turbines are operated out of SoLoNO$_x$™ mode, i.e. loaded less than 50% of MRO, such as:

- During turbine switchover events
- Turbine Start-up operations following installation shutdowns

~~During~~ Such events are expected to occur infrequently and for periods of less than an hour, however, emissions will be minimsed by preferentially running on fuel gas either via imported gas from the WoSPS pipeline or associated gas from production wells. Impacts of such operations have been considered within the emission load calculation [10] prepared as part of the PPC permit submission, using the information provided in Solar Product Information Letters (PIL), specifically those outlined in PIL 170.

During extended periods of non-production e.g. during gas compressor outages, the operating philosophy will be to load a single GTG preferentially fueled by imported fuel gas from the WoSPS pipeline. In this scenario, the GTG will operate around ~~56%~~ 28% of it's maximum rated output (based on the expected installation base load during periods of non-production, which falls below the DLE activation threshold as illustrated in Figure 5-1. During operation, approved operating procedures will be followed to minimise the likelihood of OTNOC and therefore, the time spent operating out of SoLoNO$_x$^{TM} mode- see Section 4.1.



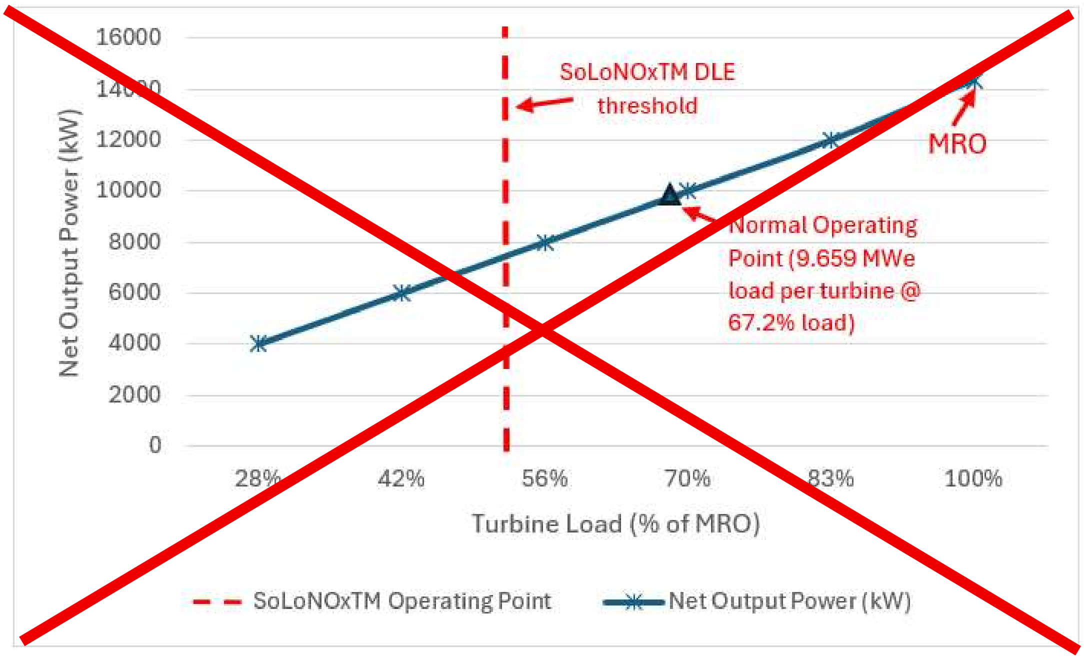


Figure 5-1 Estimated Normal Operating load Point of Rosebank FPSO Main Power Generation Turbines in relation to SoLoNO$_x$^{TM} activation threshold [13]

Thermal efficiency has been selected as the main indicator for the environmental performance of the main power generation system. Based on this efficiency, single cycle power generation is an acceptable environmental option. Emissions from turbines are dependent on the operation of the machine and some variation can be expected when air combustion or turbine load changes.

It is difficult to predict the emissions from combustion equipment prior to start-up because some variables are not known, and some information provided by suppliers may not be valid for the Rosebank FPSO.

~~There are no High Efficiency Particulate Arrestance (HEPA) filters on the gas turbines. However, they will run on fuel gas during normal operation and as such will not produce particles.~~ Filtration systems are fitted to all GTG air inlets, intended to avoid turbine fouling and reduce requirements for frequent water washes. Cam-Flo Bag filters are installed on the inlet primary filtration package with Cam-GT Box type High Efficiency Particulate Arrestance filters on the secondary system. The gas turbines are periodically washed with a dilute detergent solution to remove debris and any contamination.

It should be noted that FPSO is prepared for future electrification for further decarbonization, with all required modifications to permit electrification of the installation completed prior to the arrival of the FPSO at the field location.

5.5 Reciprocating Engines

All reciprocating diesel engines on the Rosebank FPSO are critical to the safety of the facility and are provided for emergency use only. These are run for a short time each month to test the function of the engine and to ensure any maintenance requirements are promptly addressed.

Emissions are controlled by ensuring that these engines are shut down when not in use and by using diesel fuel with low sulphur concentration (<0.1 %).

5.6 Inert Gas Generator

The inert gas generator (IGG) consumes diesel and is used to provide inert gas. It is expected to operate for around 48 [10] hours per year. IGG emissions are expected to be immaterial when compared with emissions from other equipment.

Blanketing is required for cargo tanks on board the FPSO to prevent air ingress and the formation of an explosive atmosphere in the tanks, as well as for the regulation of the pressure in the tanks. Normally, hydrocarbon gas will be used for blanketing of cargo tanks which is fed from the first stage suction scrubber for A and B compressors however, the inert gas generator will be used as back-up in the event the primary source is unavailable.

6.0 ENERGY EFFICIENCY

The Rosebank FPSO is a new facility and has been engineered to prioritise energy efficiency through the lifetime of the project. Optimisation for energy efficiency is an integral part of the Rosebank design development for all areas from subsurface to facilities and product transportation.

The design of the installation considers optimal equipment/piping sizing to achieve as best as possible energy efficient facilities, including variable speed drives for various pumps and compressors, Hydraulic driven pumps etc., to achieve intended energy efficiency. Heat conservation insulation is provided to all process equipment operating at high temperatures and winterisation insulation is provided to all equipment susceptible to icing or freezing. This reduces the heating power required and ultimately reduces the consumption of fuel at the facility.

Some ways in which energy efficiency has been optimised:

- Modifications to the redeployed FPSO.
- Phased development of wells.
- Power management systems will be provided to optimise the overall system operation.
- Heat recovery from turbine exhaust gases.

6.1 Waste Heat Recovery

Each gas turbine generator on the installation has been fitted with Waste Heat Recovery unit (WHRU) for heating of crude oil and process equipment.

The heating demand required for the Rosebank FPSO will be recovered from cooling down the main power exhaust gas using Waste Heat Recovery Units (WHRUs). The WHRUs, satisfy the heat requirements for all systems on board the FPSO under normal operation. The heating medium (Therminol 55) is heated as it flows through the WHRUs. It then flows to the process heat exchangers. The cooled heat medium then flows back to the suction of circulation pumps. An expansion tank is provided at the highest point in the system. Heating medium supply and return temperature are assumed 250 ºC and 159 ºC, respectively.

The WHRUs will be replaced by two HV Electrode boilers at a future date when on power from shore. However, they will not be removed from service as they will function as back-up solution in case of loss of power from shore. HV Electrode Boiler

The full electrification option is adopted with HV Electrode Boiler to provide heating for process and utilities. Two boilers with steam generators will provide steam. The steam will be sent to heat exchangers and then distributed across the process plant to the consumers.

6.2 Energy Management

Altera is committed to running their business in an environmentally responsible manner and energy efficiency is a key objective. This objective is cascaded down through the organisation.

Internal targets for Global Warming Potential (an indicator which considers the relative impacts of greenhouse gases) are set for each Asset and performance against target is monitored and reported.

As a participant in the Energy Savings Opportunities Scheme (ESOS), Altera is required to measure total energy consumption, conduct energy audits to identify cost-effective energy efficiency recommendations, and notify compliance to the Regulator.

7.0 ENVIRONMENTAL MANAGEMENT

The installation operator and duty holder of the Rosebank FPSO is Golar-Nor (UK) Limited, a subsidiary of Altera Infrastructure and adheres to the procedures, policies, and standards of the parent organisation. Altera is committed to preventing pollution, meeting regulatory compliance, and improving environmental performance. These commitments are outlined and implemented through Altera's Environmental Management System (EMS), which has been verified as aligned with the requirements of ISO 14001:2015.

The MS includes systems and procedures to ensure environmental risks are identified and minimised and ensures that Altera identify all relevant legislation, periodically evaluate compliance and act on any non-compliance. The system also includes processes to identify and assess operational risks to the environment and ensure appropriate measures are in place to ensure their control. Furthermore, the MS ensures the inspection and maintenance of equipment and assures the training and competence of all relevant personnel. The Asset Manager has overall responsibility for ensuring that the HSE Policy and MS is implemented within the asset. The Asset Manager is also accountable for the co-ordination and management of all activities carried out at the installation level, including compliance with the PPC permit. Specific roles and responsibilities for complying with the PPC permit conditions were developed and are cascaded as appropriate. In addition, compliance with the permit is incorporated into the internal audit programme undertaken across Altera.

8.0 OPERATIONAL MANAGEMENT

Effective operational management is key to reducing emissions. A clear management structure exists at Altera with allocated responsibilities for efficient operation of the combustion equipment and environmental performance. Experienced operators will operate the combustion equipment following approved procedures to ensure safe and reliable operation. These procedures will be documented in the Installation Operating Procedures Manual.

Key operational parameters will be monitored by a range of sensors, indicators and alarms that are displayed/indicated in a local control room. This gives operators an opportunity to respond to changes in performance and preventing excessive environmental discharges.

8.1 Training and Competency

Technically competent and trained staff under the control of the Rosebank FPSO Offshore Installation Manager will operate the combustion equipment. Each operator has an electronic profile which details compliance against the training and competence requirements for their roles, based on the requirements of ~~Shelf States~~, Flag States – the jurisdiction under whose laws the vessel is registered or licensed (The Bahamas), Clients and the Company. Operators are aware of the regulatory implications of their work.

8.2 Availability and Reliability

Availability and reliability of the individual turbines and engines are monitored utilising Original Equipment Manufacturers (OEMs) digital technology which will give end-to-end visibility allowing for rapid intervention, diagnostics with real time data availability. This information will be linked back into the Systems, Applications, and Products in Data Processing (SAP) based Central Maintenance System with any corrective actions being generated for faults and planned maintenance being implemented on time.

8.3 Maintenance

Over time, turbine internals can become contaminated, leading to a loss of performance. Turbine cleaning will be performed according to the vendor's recommendations, involving the application of a small amount of aqueous cleaning fluid, followed by a soaking and/or cranking period. The spent cleaning fluid is collected at the turbine base plate and transferred to facility drains for filtration and discharge. Typically, turbines regain their performance after cleaning.

Maintenance schedules and equipment overhauls are planned to minimize plant downtime and prevent unplanned shutdowns. These schedules consider the vendor's recommendations and operational experience. During the operational phase, the gas turbines (GTs) will be managed under a Solar contract, with overhauls and 8k services conducted by Solar.

The InSight system from Solar is a remote Advanced Diagnostics and Analytics Condition Monitoring System for the Titan 130 Gas Turbines. This will likely include management and cleaning assistance.

GT maintenance includes critical tasks, such as tracking disc run hours and performing borescope inspections. Each turbine will require a borescope inspection from a Solar engineer after 8,000 hours [12].

Gas turbines are overhauled based on OEM-recommended run hours, typically 30,000 hours for Solar, with the possibility of extending to 40,000 hours if condition-based monitoring supports it. Overhaul hours will be monitored via a Power Management System and the Solar

InSight system. The turbines are fully tested onshore before returning to offshore service, and third-party inspection intervals are strictly followed to ensure optimal performance.

8.4 Management of Change

Management of Change (MOC) requests will be registered in the Altera EMOC system, which enables each MOC to be screened and evaluated against a set of criteria. The latter includes environment, Environmental Impact, emissions of CO_2, and fuel use together with other business issues. The MOCs are reviewed by an internal multidisciplinary panel and those that pass are prioritised for execution. The system is designed to ensure that improvements are justified and implemented on the basis of best practice, asset integrity and suitability.

9.0 POTENTIAL ENVIRONMENTAL IMPACTS

9.1 Emissions to Air

The production emissions from the Rosebank FPSO on sensitive receptors, offshore and onshore, has been assessed using dispersion modelling. The results have been compared to the UK short-term and long-term ambient air quality objectives. Detailed technical information of the air quality assessment is presented in the Petrojarl Rosebank FPSO Air Quality Assessment [18].

The power demand of the main combustion equipment for the Rosebank FPSO is anticipated to be up to 70% load of the gas turbines. To ensure the air quality assessment is conservative with respect to planned operation, the Rosebank FPSO gas turbine emissions were modelled at higher power demand loads. Details of the modelled scenarios are listed below:

- Scenario 1: Normal Operations. 3 x Solar Titan 130 running on fuel gas at 84% load;
- Scenario 1b: Sensitivity Test. 2 x Solar Titan 130 running on fuel gas at 84% load plus 2x Solar Titan 130 running on fuel gas at <50% load (No DLE NO_x Technology in operation);
- Scenario 2: Non-Routine Operations. 3 x Solar Titan 130 operation running on diesel at 89% load;
- Scenario 3: Non-Routine Operations with flaring. 2 x Solar Titan 130 Operation on diesel running on diesel at 89% load with flaring. As demand is reduced, fewer turbines are required to be running.

The results of the air quality assessment showed that overall, the short-term and long-term NO_2 , SO_2 and CO Process Contributions (PCs) have been screened out as insignificant (1% of the Air Quality Standards), except for the short-term NO2 PCs during non-routine operations, Scenarios 2 and 3, (>10% of the Air Quality Standard). The NO2 Predicted Environmental Concentrations (PECs) for these two scenarios ranged between 13.6% and 24.9% of the short-term air quality standard (200 µg/m3) and therefore considered to be insignificant.

~~The changes in NO_2, SO_2 and CO concentrations at all identified sensitive human receptors, including neighbouring platforms, FPSOs, the UKCS median line, and the nearest onshore receptor, Shetland, were insignificant.~~ It is observed for all scenarios, that the NO_2, SO_2, and CO AQS limits were not exceeded at any receptor modelled. Key pollutant concentrations for all scenarios have been identified as insignificant.

9.2 Water and Discharge Use

The drain system is crucial for managing spills and free liquids to ensure the safety of the FPSO. It collects and handles hydrocarbon and water spills on deck from both pressurized equipment and open areas. The system is divided into hazardous and non-hazardous open drains, which are physically segregated to prevent hazardous material migration.

The open drain system manages rainwater, firewater, wash-down water, and spills from deck areas, equipment drip trays, and bounded areas. Hydrocarbon liquids are recovered, and only clean water is discharged to the sea. Drains from non-polluted areas are routed directly to the sea. Fluid compatibility is considered to prevent chemical reactions and solidification in the drain system.

- Hazardous Area Drains: Routed to the Hazardous Open Drain Tank.

- Non-Hazardous Area Drains: Routed to the Non-Hazardous Open Drain Tank.

These tanks are physically segregated to avoid cross-contamination. Liquid collected in both tanks is routed to the slop tank in the hull, with skimming facilities for hydrocarbons. Skimmed hydrocarbon liquid is routed to the closed drain system. Excess fluids from heavy rain or deluge are routed overboard via overflow lines to prevent overfilling, with the option to route to the slop tank for further treatment.

Deluge water is routed to the sea via overflow lines designed for full deluge capacity. Drains from non-polluted areas are routed directly to the sea. Inlet lines to both drain tanks are submerged to prevent backflow of hydrocarbon gas, and overflow lines are submerged to prevent dumping of floated oil and hydrocarbon emissions.

The closed drain system collects hydrocarbon liquid and hazardous fluid from topside equipment and piping, degasses the collected liquid, and pumps it primarily to the slop tank.

9.3 Waste Management

Liquid and solid waste, including maintenance-related waste, will be generated from turbine operations and sent to shore for safe recovery or disposal when recovery is not possible. All waste materials sent ashore will comply with duty of care regulations. There will be no significant potential impacts associated with waste disposal.

10.0 CONCLUSIONS

The power requirements for the Rosebank FPSO have been strategically evaluated during the concept select phase of the project. Gas turbine generators with dual fuel capability provide main electrical power to the facility. All turbines are provided with state-of-the-art dry low-emission (DLE) control systems to reduce environmental discharges of NO_x, SO_x, CO, and unburned hydrocarbons, and waste heat is recovered from hot exhaust gases to meet the heat duty of process equipment.

The selected equipment configuration balances emissions, efficiency, availability, reliability, and capital cost and as such, it represents the Best Available Technique to provide the Rosebank FPSO with power.

Reciprocating diesel engines are provided for equipment that only runs during emergency conditions, and an inert gas generator supplies safe combustion gases to cargo oil storage tanks to facilitate maintenance activities.

Applicability of the BAT conclusions is presented in Appendix A, and it is considered that this equipment configuration represents the Best Available Technique for reduction of emissions from the Rosebank FPSO, as defined in the BAT Reference Document [14], and offers Altera every opportunity to apply the best environmental practices throughout the lifetime of the Rosebank field.

11.0 REFERENCES

NUMBER	
1	UK Secretary of State, "The Offshore Combustion Installations (PPC) Regulations 2013 (as amended)," 2018.
2	European Commission, "Directive 2010/75/EU on Industrial Emissions (Integrated Pollution Prevention and Control)," 2010.
3	Rosebank FPSO Offshore Pollution Prevention Control Permit (PPC/~~352~~ 123)
4	eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2015:313:FULL Medium Combustion Plant Directive
5	~~Department for Energy Security & Net Zero (DESNZ) has published an offshore specific guidance note~~ Offshore Pollution Prevention and Control (PPC) Guidance, Department of Energy Security & Net Zero (DESNZ), August 2023
6	Rosebank_Environmental_Statement_-_Final_for_Submission_To_OPRED_Equinor_3rd_August_2022
7	Predictive Emissions Monitoring Systems (PEMS) Technical Note, OEUK 2023
8	BAT Assessment - 0D204-AKR-S-00-RA-000035_F02_IFD_2022-10-26_01
9	0D204-ABB-E-82-LA-000002_P04_IFC_2025-04-21_02 - Electrical Load List
10	Email Correspondence: DB Email with Rosebank - Combustion Emissions Forecast
11	0D204-KAN-P-00-LA-000001 Utility Consumption List
12	GL Comments on: Rosebank Data Request 16.09.25
13	Solar Predicted Engine Performance TITAN_130-20501S_New Gas Fuel_ISO Inlet Conditions.pdf
14	EU. (2017). Best Available Techniques (BAT) Reference Document for Large Combustion Plants.
15	D204-AKR-S-00-RA-000035 – BAT Assessment (ROSEBANK DEVELOPMENT FPSO FEED)
16	PM731-PMS-050-003, Rev. 06, Final, Design Basis Knarr redeployment concept – Rosebank project
17	The Greenhouse Gas Emissions Trading Scheme (Amendment) Order 2020
18	221267C-001-RT-6200-0001 - Petrojarl Rosebank FPSO Air Quality Assessment
19	Product Information Letter (PIL) 170 - EMISSION ESTIMATES START UP SHUT DOWN (Solar Turbines)

APPENDIX A – BAT CONCLUSIONS

BREF SECTION NO.	BAT NO.	BAT CONCLUSION/DESCRIPTION	APPLICABLE SECTION OF BAT
Evidence of techniques used/ considered to reduce NOx and/ or CO emissions to air and consumption & from combustion of gaseous fuels on offshore platforms			
3.1.4 & 7.4.3.3	No Specific BAT	Direct Water/Steam Injection	N/A
		Dry Low NOx burners (DLN/DLE)	4.1
		Selective Catalytic Reduction (SCR)	N/A
		Combustion Optimisation	4.1, 5.4
		Predictive Emission Monitoring System (PEMS)	5.1
Evidence of techniques used/ considered to increase efficiency on offshore platforms			
7.4.3.2	No Specific BAT	Power integration of multiple fields or platforms	6.0
		Optimisation of energy-consuming equipment	6.0
		Water heat recovery	6.1
BAT conclusions for the combustion of gaseous and/or liquid fuels on offshore platforms to prevent or reduced NOx emissions (BAT 52, 53) and CO emissions (BAT 54) - BAT is to use one or a combination of the techniques given			
10.4.3	BAT 52	Process Optimisation	4.1,6.1
		Control Pressure Loses	4.0
		Load Control	4.1
		Minimise spinning reserve	3.1 and 4.1
		Fuel choice (i.e. low sulphur fuel)	5.2, 5.3
		Heat Recovery	4.1.4, 6.1
		Power integration of multiple gas fields	6.0
	BAT 53	Advanced Control System	See Section 5.0
		Dry -Low NOx burners (DLN/DLE)	4.1, 5.4
		Lean burn concept (only applicable to new gas-fired engines)	N/A
		Low NOx burners (only applicable to boilers)	N/A
	BAT 54	Combustion Optimisation	4.1, 5.4
		Oxidation Catalysts	N/A
General BAT Conclusions (BREF Section 10.1)			
10.1.1	BAT 1	In order to improve the overall environmental performance, BAT is to implement and adhere to an environmental management system (EMS) that incorporates all of the features as given under BAT 1.	7.0
Monitoring			

10.1.2	BAT 2, 3	Efficiency, and key process parameters to be monitored.	6.0
	BAT 4	The frequency of monitoring is given in BAT 4 for combustion plants on offshore platforms.	Please refer to the Emissions Monitoring Plan as per this PPC Permit Application
General Environmental and Combustion Performance			
10.1.3	BAT 6	In addition to BAT 52, and in order to improve the general environmental performance of combustion plants and to reduce emissions to air of CO and unburnt substances, BAT is to ensure optimised combustion and to use an appropriate combination of the techniques given in BAT 6.	4.1
	BAT 7	If the use of selective catalytic reduction (SCR) or selective non-catalytic reduction (SNCR) is used, to reduce emissions of ammonia to air, BAT is to optimise the design and/or operation of SCR and/or SNCR.	N/A
	BAT 8	In order to prevent or reduce emissions to air during normal operating conditions, BAT is to ensure, by appropriate design, operation and maintenance, that the emission abatement systems are used at optimal capacity and availability.	See Section 8.0
	BAT 9	In order to improve the general environmental performance of combustion and/or gasification plants and to reduce emissions to air, BAT is to include the elements listed in BAT 9 in the quality assurance/quality control programmes for all the fuels used, as part of the environmental management system (see BAT 1)	See Section 5.0
	BAT 10	In order to reduce emissions to air and/or to water during other than normal operating conditions (OTNOC), BAT is to set up and implement a management plan as part of the environmental management system (see BAT 1), commensurate with the relevance of potential pollutant releases, that includes BAT 10 for the elements covered in BAT 10.	See Section 9.0
	BAT 11	BAT is to appropriately monitor emissions to air and/or to water during OTNOC.	See Section 9.0
Energy Efficiency			
10.1.4	BAT 12	In order to increase the energy efficiency of combustion, gasification and/or IGCC units operated ≥ 1 500 h/yr, BAT is to use an appropriate combination of the techniques given.	See Section 6.0
Water usage and emissions to water			
10.1.5	BAT 13, 14	In order to reduce the water usage and the volume of contaminated wastewater discharge, BAT is to use one or both of the techniques given.	See Section 9.0

		In order to prevent the contamination of uncontaminated wastewater and to reduce emissions to water, BAT is to segregate wastewater streams and to treat them separately, depending on the pollutant content.	
Water usage and emissions to water			
10.1.6	BAT 16	In order to reduce the quantity of waste sent for disposal from the combustion and/or gasification process and abatement techniques, BAT is to organise operations so as to maximise, in order of priority and taking into account life cycle thinking.	See Section 9.0