Shell Penguins – Best Available Techniques (BAT) Assessment (PPC/113)

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Penguins BAT Assessment for Combustion Plant

May 2024

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ABBREVIATIONS

BAT	Best Available Techniques
BAT-AEL	BAT Associated Emission Level
BATc	BAT Conclusions
BAU	Business as Usual
BREF	BAT Reference Document
CAPEX	Capital Expenditure
CBA	Cost Benefit Analysis
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DESNZ	Department for Energy Security and Net Zero
DEFRA	Department for Environment, Food and Rural Affairs
DGS	Dry Gas Seal
DLE	Dry Low Emissions
EAJ	Environmental-Assessment Justification
ELVs	Emission Limit Values
EMS	Environmental Management System

ESOS	Energy Saving Opportunity Scheme
FEED	Front End Engineering Design
FGI	Fuel Gas Import (project)
FWP's	Fire Water Pumps
H_2S	Hydrogen Sulphide
HEPA	High Efficiency Particulate Arrestance
IED	Industrial Emissions Directive
ISO	International Organization for Standardization
KPI	Key Performance Indicator
LCP	Large Combustion Plant
MAT	Master Application Template
MMSCFD	Million standard cubic feet of gas per day
MOC	Management of Change
MW	Megawatts
MW_{th}	Megawatt (thermal)
NMVOCs	Non-Methane Volatile Organic Compounds
NO_2	Nitrogen Dioxide
NO_x	Nitrogen Oxides
OCGT	Open Cycle Gas Turbines
OEM	Original Equipment Manufacturer
OIM	Offshore Installation Manager
OPEX	Operating Expenditure
OPRED	Offshore Petroleum Regulator for Environment and Decommissioning
OTNOC	Other Than Normal Operating Conditions
PPC	Pollution Prevention and Control
PPC Regulations	The Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 2013 (as amended)
SAC	Standard Annular Combustion
SAP CMS	System Analysis Program Central Management Server
SCE	Safety Critical Equipment
SAT	Subsidiary Application Template

SCR	Selective Catalytic Reduction
SO_x	Oxides of Sulphur
UHC	Unburnt Hydrocarbons
UKCS	United Kingdom Continental Shelf
ULSD	Ultra-Low Sulphur Diesel
VRU	Vapour recovery Unit

1. Project Description

The Penguins field refers to a cluster of fields, Penguin A, C, D and E, located in UKCS block 211/13a and 14, around 160 km northeast of the Shetland Islands and adjacent to the UK/Norway median line. The Penguins field was discovered in 1974 and first developed in 2002. At that time oil and gas were pumped from four drill centres that were tied back to Brent Charlie platform in the nearby brent field. In 2017, after 40 years of successful operation, Shell started the process of decommissioning the Brent field, including the Brent Charlie platform. In 2018 Shell took the decision to redevelop the Penguins oil and gas field using a floating production, storage, and offloading (FPSO) vessel that would take the place of the Brent Charlie platform. Shell operates the fields under a 50/50 joint venture agreement (JV65) with Neo Energy Group.

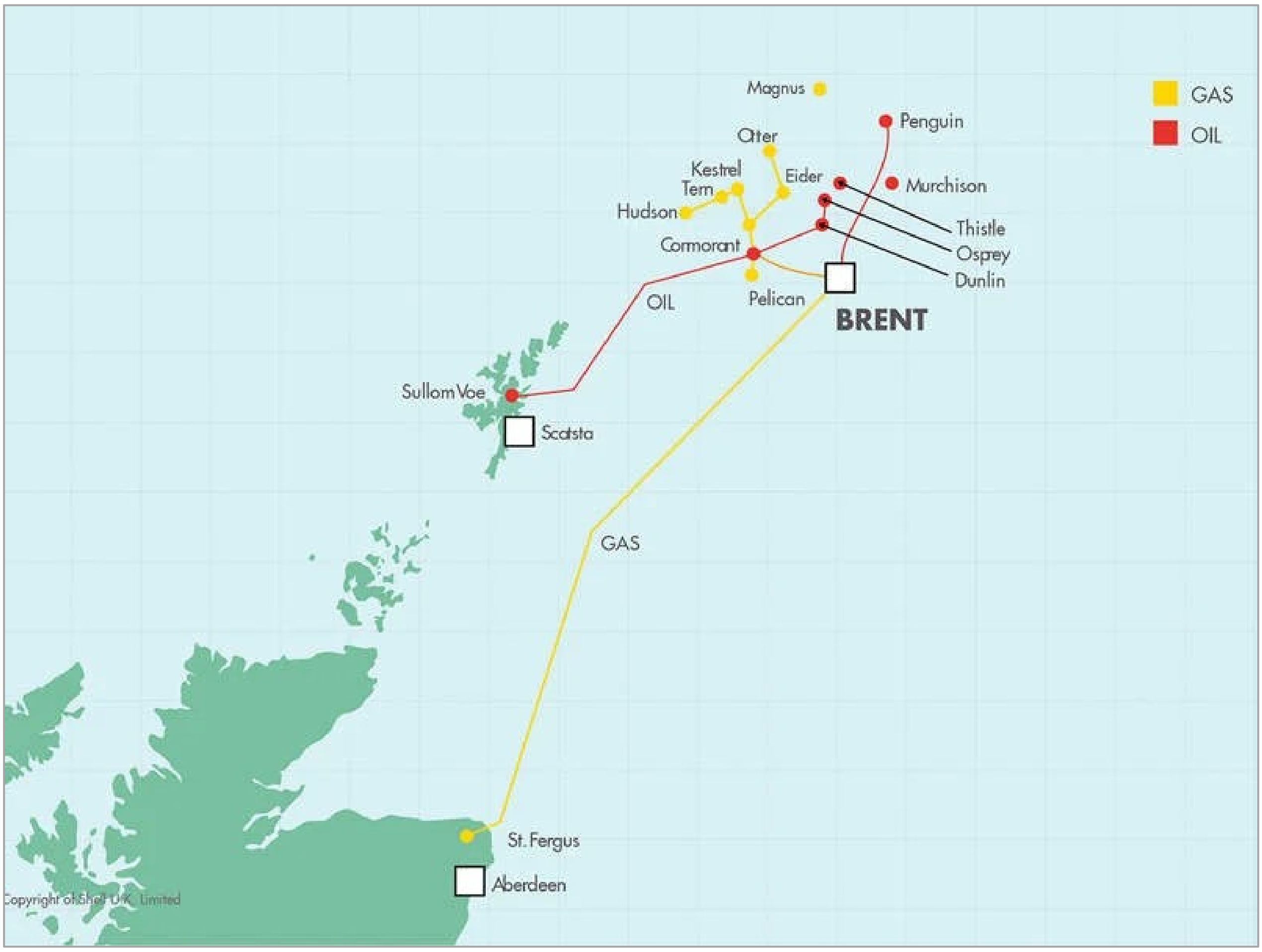

Figure 1 Penguins Field Location Map

Fluids are produced via a host floating, production, storage, and offloading (FPSO) vessel from nine existing wells (two of which are no longer producing) and nine new wells which are tied back via subsea infrastructure separated into two systems, North and South. Oil will be transported via tanker to refineries, and gas will be transported via the Far North Liquids and Associated Gas System (FLAGS) pipeline to the St Fergus gas terminal in northeast Scotland. When the FPSO becomes gas deficient or is shutdown, gas can be imported from the FLAGS system.

The selected FPSO concept is a newly built, JV owned and Shell operated Sevan 400 type FPSO (see Figure 2) with a 20-year design life. The hull is a purpose-built, circular hull with 400,000 barrels of oil storage capacity. The topsides facility has a design processing capacity of approximately 35,000 barrels of oil per day and 120 MMSCFD of gas per day.

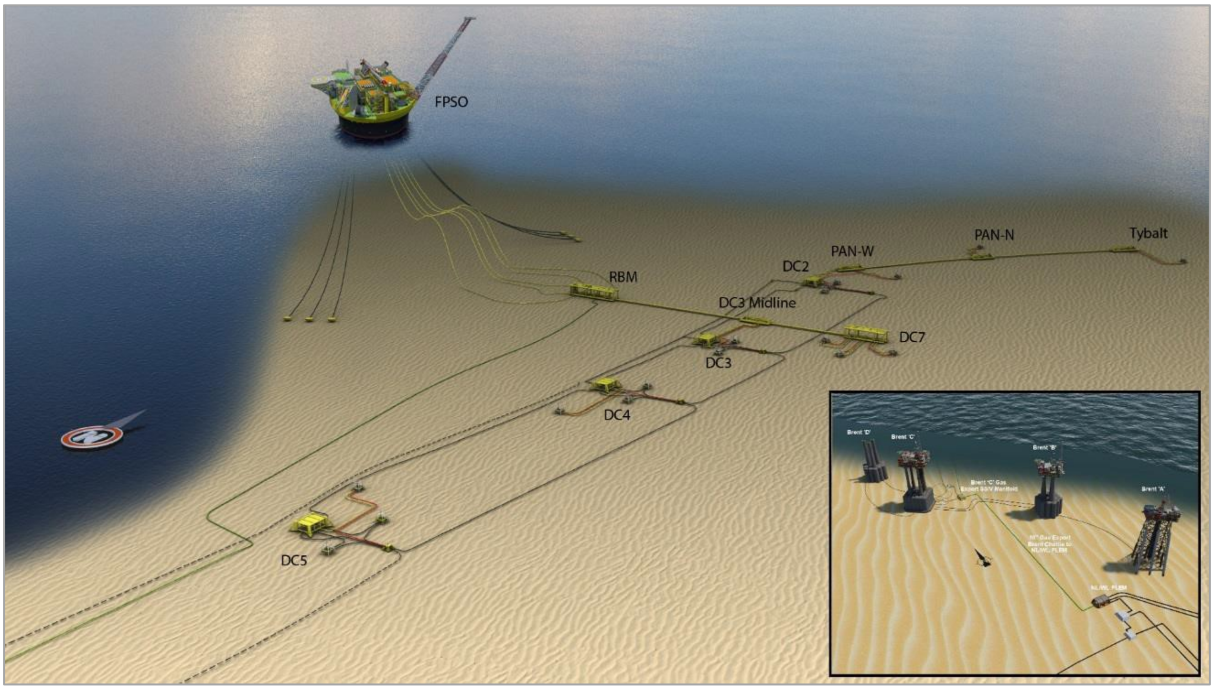

Figure 2 Penguins Redevelopment Field Schematic (not to scale)

The main power supply is obtained from the Taurus 70 Gas Turbine Generators (GTGs) in a 3 x 50% configuration. Normally, two machines are running with the vessel load shared to ensure stable production and minimise generated emissions. Power supply from near-by installations was considered during the design phase but was deemed not feasible.

The HP gas compression turbine driver is a Titan 130 gas-fired turbine (1 x 100% configuration). Both the power generation and gas compression turbines are fitted with Solar's $SoLoNO_x^{TM}$ 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 the gas turbines normally operate on gas minimising the emissions of SO_2 from this combustion equipment. Low Sulphur diesel (< 0.1 wt.%) is also used as a back-up fuel source for gas turbines infrequent events where enough fuel gas is not available.

To reduce the emissions from the asset, a Vapour Recovery Unit (VRU) has been installed to recover waste streams which would otherwise historically have been routed to flare. The VRU compresses fuel gas which has been used for blanketing the vapour space in the oil cargo tanks and as stripping gas in the TEG regeneration unit and feeds it into the gas compression train.

There are 3 diesel driven fixed speed electrical firewater pumps (FWPs). When there is a demand, one firewater pump is sufficient for full FPSO coverage. The design of the FWP Engine enables one of the diesel engines to function as an essential generator, providing power in a black start scenario, and one of the pumps (Fire pump A-7101A) can be used as a back-up seawater lift pump. The diesel driven emergency generator is available for emergency power. The emergency generator will switchover with auto synchronisation with the GTG's, to allow for changeover of from diesel to gas generation.

The FPSO also has an inert gas generator (IGG) to provide a low oxygen atmosphere in the cargo tanks of the FPSO to minimise the risk of explosion. The IGG operates on diesel/gas oil and is expected to operate for around 1500 hours per year.

Facility heat load for Topsides/Hull processing operations is recovered from the main power turbine exhaust gas using waste heat recovery units (WHRUs). At low power load, turbine controls prioritise a high exhaust gas temperature to ensure that there is enough heat recovery at the WHRUs to avoid process upsets. A trim cooler is used to control the temperature by rejecting excess heat to the sea via the cooling medium system.

Air dispersion modelling has been undertaken to assess the impacts on air quality of emissions to atmosphere from the Penguins FPSO and has shown that pollutant levels from the FPSO are insignificant and any resulting trans boundary impacts negligible.

2. Objectives

Combustion plant on the Penguins FPSO must comply with The Offshore Combustion Installations (Pollution Prevention and Control) Regulations 2013, as amended. The Regulations transpose the requirements of both the Industrial Emissions Directive (IED) and the Medium Combustion Plant Directive (MCPD). 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 Plant (LCP) (including under IED Chapter 3) and the LCP BAT Reference (BREF) document), Medium Combustion Plant (MCP) and other qualifying combustion plant.

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 plant on the LCI such as power generation and compression gas turbines, engines, and boilers.

This report describes the process undertaken to select the Penguins combustion plant and demonstrates that environmental emissions are mitigated by applying the Best Available Techniques (BAT). The turbine selection process is described in Appendix A. This process was undertaken during the project phase and used estimated loads as estimated at that stage of the project. The Normal and Offloading load remains the same, but the estimated Normal Operational load has reduced.

The aggregation rules stated within the PPC regulations provides context to when installations are considered an MCI/LCI and when a BAT assessment is required. These rules come from 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.

- *"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.

As the combined thermal input of the main combustion plant (3 x Gas Turbine Generators each with maximum thermal input of 23.84MW$_{th}$ and 1 x HP Gas Turbine Compressor with maximum thermal input of 42.2MW$_{th}$ (GTC), which exceeds 50MWth, the FPSO is considered an LCI. However, the individual thermal rating of each turbine is less than 50MWth and because these turbines are situated offshore, they are not classed as MCP. Therefore, there are no statutory emissions limits that are applicable for these turbines, but the Regulator may set emission limit values as a condition in the PPC permit. As Penguins 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 B 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.

3. Best Available Techniques

The PPC Regulations 2013 as amended transpose the relevant provisions of the Industrial Emissions Directive 2010/75/EU (IED) (European Commission, 2010) with respect to specific atmospheric pollutants from offshore combustion installations with total thermal capacities exceeding 50 megawatts (MWth). 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 (UK), 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;

'techniques' includes both the technology used and the way in which the offshore combustion installation is designed, built, maintained, operated, and decommissioned.

BAT for a given industrial sector are described in BAT reference document (BREF). 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.

Emissions to air from combustion equipment have the most significant impact on the environment and the pollutants of most interest are:

- Oxides of nitrogen (NOx), and other compounds containing nitrogen;
- Sulphur Dioxide (SO_2), and other compounds containing sulphur;
- Carbon monoxide (CO);
- Methane (CH4) and non-methane Volatile Organic Compounds (nmVOCs); and
- Particulate Matter (PM).

This document considers the impact of NOx, CO, and SOx emissions from the Penguins FPSO as well as the energy performance of the installation. These inputs are used to demonstrate that BAT is achieved.

4. Turbine Assessment Methodology

Before the start of detailed engineering, several studies were undertaken to determine the power requirements for the Penguins FPSO process, utility, and accommodation systems. These studies culminated in the Rotating Equipment Type Selection Report (Shell UK, 2015), which determined that the following turbines were required:

- Gas-fired power turbine for the high-pressure gas compressor (1x100% configuration).
- Gas Turbine Generators (GTGs) for the main power supply to the Penguins FPSO (3x50% configuration).

The considered gas turbines for both HP compression and power generation have been evaluated against the following criteria:

- 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).
- Emissions to Air – < DLE 25 ppm.
- Fuel Quality
- Cost – lowest cost.

High efficiency gas compressor trains and process equipment have been studied and selected to minimize power demand and environmental pollution. Selection of the gas turbine driver for gas compression was based on minimum fuel gas usage during the expected field life.

Turbine screening was carried out according to the following scoring scale:

- Red – technology unsuitable based on ability to meet desired criteria. Eliminated from further consideration.
- Amber – technology partly meets desired criteria.
- Green – technology considered suitable in terms of meeting desired criteria.

The details of the selection process are presented in Appendix A and summarised below.

4.1. HP Compression

The Titan 130 Compressor has been selected to provide power to the HP compressor. The turbine is fitted with Solar's SoLoNOx™ Dry Low-Emission (DLE) combustion technology which is optimised to reduce emissions by tightly controlling the combustion temperature inside the turbine. Combustion gases are discharged to the local environment through a stand-alone discharge stack to ensure all components are dispersed. Ports in the exhaust stack are provided to enable sampling of effluent gases with a traversing probe.

4.2. Main Power Supply

The Solar Taurus 70 turbine, by Solar, was selected to power the main generators in a 3 x 50% configuration. These turbines are fitted with Solar's SoLoNOx™ Dry Low-Emission (DLE) combustion technology which is optimised to reduce emissions by tightly controlling the combustion temperature inside the turbine. Normally two machines are running with the load shared. One machine is normally on cold stand-by. Running hours are shared across the machines and there may be some situations, like change-over, when all three machines run together for a short period of time. Combustion gases are discharged to the local environment through a stand-alone (one per gas turbine) discharge stack to ensure all components are dispersed and to enable maintenance of stand-by turbines without a facility-wide shut-down. Ports in the exhaust stacks are provided to enable sampling of effluent gases with a traversing probe.

5. Combustion Plant

The aggregated thermal input of the combustion plant on the Penguins FPSO classes it as a large combustion installation. All individual combustion plant on the FPSO are neither large combustion plant (LCP) nor medium combustion plant (MCP). The combustion plant on the FPSO is listed in Table5-1.

Table5-1 Penguins Combustion Plant equipment details

Equipment Name and Model	Fuel Type	*Max Rated Output (MW)	*Maximum Thermal Input (MW_{TH})	Rated Thermal Efficiency %	Annual Running Hours-
Gas Turbine Generator, EG8001A Make: Solar Turbines Model: Taurus 70-10301S	*Fuel gas with diesel back-up*	*7.3* (1)	23.84(1)	32% (1)	Approx. 8760 hours
Gas Turbine Generator, EG 8001B Make: Solar Turbines Model: Taurus 70-10301S	*Fuel gas with diesel back-up*	*7.3* (1)	23.84(1)	32% (1)	Approx. 8760 hours
Gas Turbine Generator, EG 8001C Make: Solar Turbines Model: Taurus 70-10301S	*Fuel gas with diesel back-up*	*7.3* (1)	23.84(1)	32% (1)	Stand-by
HP Compressor power turbine, KG-2601 Make: Solar Turbines Model: Titan 130-20502S	*Fuel gas*	*15.9*(4)	42.2(2)	36%*	Approx. 8760 hours
Emergency diesel generator, A-8401 Make: MTU Model: 16V4000 P833A	*Diesel*	*1.95*(3)	5.14(3)	38%	150 hours for testing and start-up
Firewater pump diesel generator, A-7101A Make: MTU Model: 16V4000 P83 3B	*Diesel*	*2.32*	5.6	41%	56 hours for testing
Firewater pump diesel generator, A-7101B Make: MTU Model: 16V4000 P83 3B	*Diesel*	*2.32*	5.6	41%	56 hours for testing
Firewater pump diesel generator, A-7101C Make: MTU Model: 16V4000 P83 3B	*Diesel*	*2.32*	5.6	41%	56 hours for testing
Inert Gas Generator, A-6402 Make: Wärtsillä Moss AS Model: Moss Inert Gas Generator	*Diesel*	*Not applicable*	2.42	N/A	1500 hours
Generic Emissions Source – Temp Equipment	Diesel	N/A	N/A	N/A	N/A

(1) Ref 3

(2) Ref 9

(3) Ref 12

(4) Ref 11

*The inputs and outputs are based on vendor data for the GTG's and GTC at -7 deg C.

5.1. Main Power Generation

The peak electrical power demand for the Penguins FPSO is estimated to be 8.35 MW. Peak power demand is during peak production and offloading operations, offloading will be carried out weekly in early production and will take approximately one day.

Weekly offloading is expected to last for the production plateau period which is expected to be the first 18 months. The frequency of offloads will be proportional to the production rate.

The electrical power will be provided by the 3 x 50% Solar Taurus 70 Turbines which each have a maximum power output of 6.45MW @ 24DegC ambient temperature which is expected to be the maximum ambient temperature for the Penguins FPSO location.

The Turbines are normally fuelled by either produced gas or back flowed gas from the export pipeline gas. When fuel gas is unavailable (i.e. on a restart from a shutdown or an issue in the fuel gas system) the machines can be driven by liquids fuel (diesel).

The turbines have been fitted with Solar's SoLoNOx™ Dry Low-Emission (DLE) combustion technology which optimises conditions within the turbine to reduce the atmospheric emissions of pollutants when operating at loads above 50% when fuelled by gas and when fuelled by liquids. When operating at loads below 50% on gas and 65% on liquid, the engines parameters are controlled to maintain stable operation. When at these lower loads, NOx can range from 40 to 70 ppm (raw) and CO and UHC emissions can vary from 25 to 10000 ppm (raw) (Ref 6). These ranges are for all Solar engines that contain SoLoNOx™ technology and not specific to the Taurus 70.

The maximum power requirement of the Penguins FPSO whilst offloading (8.35MW) will require two machines to be running. The normal load during peak production, when not offloading, is 6.28MW. This would leave almost no spinning reserve if operating with one generator onload. To mitigate process upsets and the resulting flaring (i.e. an LP compressor trip as a result of the load shedding philosophy) two generators will be run at all times with the third in cold standby. To maximise the advantage of the SoLoNOx™ technology, the operating philosophy built into the automatic control system will operate one machine at a higher load (greater than 60%) and allow the other machine to take up the remaining load.

Expected Spinning Reserve for Single Generator Operations are assessed in Table 5-2 (Ref 2).

Table 5-2 Expected Spinning Reserve

Ambient Temperature	GTG Output Capacity	Spinning Reserve Of One GTG		
		Holding and Offloading	Holding Mode Only With Crude Oil Heating	Holding Mode Only without HPU Power Packs
-7 °C	~ 7,850 Kw	Less than zero	1,066 to 1,270 kW	1,455 to 1,659 kW
0 °C	~7,500 Kw	Less than zero	716 to 920 kW	1,105 to 1,309 kW
13 °C	~ 6,850 Kw	Less than zero	66 TO 270 kW	455 to 659 kW
14 °C	~ 6,800kW	Less than zero	16 to 220 kW	405 to 609 kW

Ambient Temperature	GTG Output Capacity	Spinning Reserve Of One GTG		
		Holding and Offloading	Holding Mode Only With Crude Oil Heating	Holding Mode Only without HPU Power Packs
24 °C	6,684 kW	Less than zero	Less than zero	89 to 293 kW

Combustion gases from these turbines are discharged to the local environment through stand-alone discharge stacks (one per gas turbine) to ensure all components are dispersed and to enable maintenance of stand-by turbines without a facility-wide shut-down. Ports in the exhaust stacks are provided to enable sampling of effluent gases with a traversing probe.

5.2. HP Compression

Penguins only has a single gas compression train hence its operation will be determined by the process duty imposed on it. The maximum power demand from the HP compressor is predicted to be 15,900 kW in early field life, falling to around 9,433 kW in later years. The turbine is fitted with Solar's SoLoNOx™ Dry Low-Emission (DLE) combustion technology which is optimised to reduce emissions by tightly controlling the combustion temperature inside the turbine. Combustion gases are discharged to the local environment through a stand-alone discharge stack to ensure all components are dispersed. Ports in the exhaust stack are provided to enable sampling of effluent gases with a traversing probe.

5.3. Reciprocating Diesel Engines

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

- Independence from process systems.
- Short start-up time.
- Stand-alone functionality.

Diesel engines provide an efficient and field-proven solution for these applications. Each is provided with fuel storage in a skid-mounted day-tank, starting systems and engine management controls. Each engine is provided with a stand-alone discharge stack.

In an emergency situation the emergency Generator provides essential power supplies to equipment deemed critical for life support on the vessel. The restart of the production is provided by the dual purpose Fire Pump Package EG-7101A which has three modes of operation and differs from the other two FWP packages as the alternator and motors are connected via the High Voltage switchboard. The addition of the switchgear allows the package to be utilised as a Fire Pump, Seawater Lift Pump or Restart Generator depending on the requirement of the situation.

5.4. Inert Gas Generator

Under normal operation, LP fuel gas is the primary means of supplying hydrocarbon blanketing gas to the oil storage tanks, however, in the event of a plant shutdown and blowdown, the inert gas generator (IGG) package A-6402 provides a large quantity of safe, inert gas to maintain a slight positive pressure in cargo storage tanks during cargo oil offloading or during preparation for maintenance. Diesel fuel is burned with atmospheric air in a combustion chamber to create inert combustion gases that contain low concentrations of oxygen. Inert gas is scrubbed and cooled by direct contact with seawater before it is transferred to the cargo tanks.

On the Penguins FPSO, cargo tank pressure control is normally achieved by recovering and compressing hydrocarbon gas (during cargo loading) and by adding fuel gas (when cargo offloading). The inert gas generator is not expected to run normally and provides a back-up for blanketing gas when fuel gas is not available. 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. 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 inert gas deck seal during a shutdown.

6. 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 SOx 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 Penguins reservoir is not sour and contains only low amounts of sulphur. To mitigate the production of SOx when running on liquid fuel, the Penguins FPSO will exclusively run all liquid fuelled combustion equipment on low sulphur diesel (0.1%).

The discharge levels of NO_x, CO and UHCs are best mitigated in the design and selection of the combustion equipment. To reduce the production of NOx and CO/UHC, the Gas Turbine Generator and Gas Turbine Driver for the HP compressor have all been purchased with the inclusion of Solar's $SoLoNO_X$ technology which optimizes the performance of the combustion and fuel systems within the package to reduce NOx, CO and UHCs at high loads without jeopardising stability or transient capabilities. To maximise the advantage of the SoLoNOx™ technology, the operating philosophy built into the automatic control system will operate one GTG at a higher platform load (greater than 60%) and allow the other machine to take up the remaining load. This approach is expected to mitigate the CO and NOx concentrations that can increase at low turbine loads, i.e. when SoLoNOx controls are not active.

Fuel consumed on Penguins is metered using instrumentation that is managed and maintained to meet the strict requirements of the GHG Order, as amended. Where required, fuels are also sampled so that composition can be monitored in line with the requirements of the GHG Order. Fuel gas is also treated 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. 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.

6.1. 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 characteristic, 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 (Ref 14). During the design phases of the FPSO no tested and approved PEMS were identified and hence use of PEMS was not considered BAT. Shell will review its position as the PEMS market evolves.

6.2. Fuel Gas

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

- Fuel supply to the HP compressor power turbine
- Primary fuel supply to GTGs
- Blanketing gas for cargo tanks during offloading.
- Pilot gas and back-up purge gas for flare systems.
- Seal gas for HP compressor dry-gas seals during start-up or pressurized shutdown (with partial blowdown).
- Stripping gas for the glycol regeneration system.

Fuel gas composition (Ref 10) is expected to be stable, but some changes can be expected during the life of the development. The expected composition is shown in Table 6-1.

Table 6-1 Fuel Gas composition

Component	Mole percent
Methane	71.80
Ethane	13.21
Propane	8.42
Carbon Dioxide	2.48
n-Butane	2.11
Nitrogen	0.78
i-Butane	0.76
i-Pentane	0.20
n-Pentane	0.20
C6+	0.00
Water Vapour	0.00
Hydrogen Sulphide	0.00

6.3. Diesel

Low sulphur diesel conforming to DMA ISO 8217, with a maximum sulphur concentration of 0.1% (Ref 8), is transferred to the Penguins FPSO from supply boats. It is permanently stored in tanks for distribution and consumption when required. Diesel fuel is used to supply equipment that is not intended to be run continuously:

- Fire water pumps (A-71401A/B/C)
- Solar Taurus Duel Fuel Generators
- Emergency diesel generator. (A8401)
- Inert gas generator (~~A-8401~~ A-6402)

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, Diesel is also supplied to life-boat stations for re-fuelling. All diesel supply to the FPSO and consumption by combustion plant (i.e., GTGSs), is accurately metered.

6.4. Turbines

The turbines installed on the Penguins FPSO employ state-of-the-art technology to deliver high efficiency and low emissions. Solar's SoLoNOx™ dry low-emission 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).

Emissions from turbines are dependent on the operation of the machine and some variation can be expected when combustion air temperature 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 Penguins FPSO.

HEPA-12 filtration systems are fitted to each turbine and low pressure drop exhaust systems are fitted that minimise pressure losses.

Atmospheric emissions will be higher when the Taurus 70 turbines are operated using liquid fuel; these are estimated as 96 ppm NO_x, 50 ppm CO and 25 ppm UHCs when the turbine is at full load (Ref 7). Liquid fuel is provided as a back-up and is only expected to be used for short periods of time when import gas is unavailable to enable start-up or to prevent an uncontrolled shut- down of the Penguins FPSO. The number of hours the turbines are operated in liquid fuel mode is recorded and strictly limited.

6.5. Reciprocating Engines

All reciprocating diesel engines on the Penguins FPSO are critical to the safety of the facility and are provided for emergency use only. These are run for a short time each week 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 %).

6.6. Inert Gas Generator

The inert gas generator (IGG) consumes diesel/gas oil and is used to provide a low oxygen atmosphere in the cargo tanks of the FPSO to minimise the risk of explosion. It is not classed as MCP (Ref. 4) and is expected to operate for around 1500 hours per year. Emissions from the IGG are expected to be immaterial when compared with emissions from the gas turbines on the FPSO. There is no sampling port fitted to the IGG so stack monitoring is not possible. However, O2 levels will be monitored to validate that the IGG is operating as per design.

7. Energy Efficiency

The Penguins FPSO is a new facility and has been engineered to prioritise energy efficiency through the lifetime of the. Design considers optimal equipment/piping sizing to achieve as best as possible energy efficient, facilities include 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.

Heat duty required continuous operations of process equipment is met by heat recovery from turbine exhaust gases, so there is no external heat source. The peak heat recovery is approximately 15.6 MW which is used to supply heating medium to-end consumers.

The efficiency of the turbines themselves is only one of the factors of the total energy efficiency of the offshore installation.

7.1. Waste Heat Recovery Unit

Each gas turbine generator has been fitted with Waste Heat Recovery system for heating crude oil.

The heating demand required for the Penguins facility will be recovered from cooling down the main power exhaust gas using Waste Heat Recovery Units (WHRUs). The WHRUs, heat circulating fluid (heating medium) which supplies the normal process heat duty to FPSO topsides equipment and cargo storage systems.

The heat load is expected to increase by approximately 25% in the first three years as production reaches peak and plateaus off. Heating load is then expected to decrease back to initial levels in late file time (approx. 20 years' time). The increase in heat load is a result of lower fluid velocities subsea which increases the amount of heat required to achieve effective separation once the well fluids are on the production module. The heat requirement will change because of infill wells to extend the production plateau from the existing reservoir or future tie back of new developments to the FPSO.

7.2. Energy Management

Shell is committed to running their business in an environmentally responsible manner and energy efficiency is a key objective. This objective is cascaded down throughout the organisation. A Shell Group Exploration & Production energy efficiency Key Performance Indicator (KPI) is tracked and managed on a regular basis. This KPI is published on the Shell web site, which can be accessed by the public.

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), Shell is required to measure total energy consumption, conduct energy audits to identify cost-effective energy efficiency recommendations, and notify compliance to the Regulator.

8. Environmental Management

Shell is committed to preventing pollution, meeting regulatory compliance, and improving environmental performance. These commitments are outlined in Shell's HSE Policy and achieved through the implementation of Shell's Environmental Management System (EMS).

Shell's commitment to improving environmental performance is achieved through Shell's HSE Planning process, which ensures that Shell establishes, and monitors achievement of, objectives and targets for improvement. Objectives and targets are set at a strategic level and cascaded down to asset level.

The EMS ensures that Shell identify all relevant legislation, periodically evaluate compliance and act on any non-compliance. This also ensures that environmental aspects and appropriate operational controls to prevent pollution are identified.

The Asset Manager has overall responsibility for ensuring that the HSE Policy and EMS 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 Shell UK's business.

9. Operational Management

Effective operational management is key to reducing emissions. A clear management structure exists at Shell 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 Platform 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.

9.1. Training and Competency

Technically competent and trained staff under the control of the Penguins FPSO Offshore Installation Manager will operate the combustion equipment. Each operator has a personal training record containing details of qualifications, courses attended and other relevant information. Operators are aware of the regulatory implications of their work.

9.2. Availability and Reliability

Availability and reliability of the individual turbines and engines are monitored utilising OEM's 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 SAP based Central Maintenance System with any corrective actions being generated for faults and planned maintenance being implemented on time.

9.3. Maintenance

Over time the turbine internals become contaminated resulting in a loss of performance. Turbine cleaning will be conducted in accordance with vendor's recommendations, and this involves the application of a small quantity of aqueous cleaning fluid followed by a period of soaking and / or cranking. Spent cleaning fluid is recovered to the turbine base plate and transferred to the facility drains for filtration and discharge. Following cleaning, turbines normally recover any loss of performance.

Maintenance schedules and overhaul of the equipment are programmed to reduce plant unavailability and avoid unplanned shutdowns. The maintenance schedules take account of the vendor's recommendations and experience gained from operating the equipment. In the operate phase the GTs will fall under the Solar managed contract. Therefore, the overhauls and the 8k services will be conducted by Solar.

Maintenance of the GTs includes the Safety Critical Equipment (SCE) related tasks, inclusive of tracking disc run hours, and borescope inspections.

Gas turbines are sent for overhaul based upon OEM recommended run hours, typically 30,000 hrs. for Solar, with an option to extend out to 40,000 hrs if condition-based monitoring supports this decision. The turbines are fully tested onshore before being returned to offshore service and the third-party inspection intervals are rigorously adhered to. This ensures that maximum performance is achieved from the equipment. Overhaul reports are available for each of the gas turbines.

9.3.1 Gas Turbine Water Wash

HEPA-12 filtration systems will be fitted to all GT drivers intended to avoid compressor fouling and hence compressor washing. Low pressure drop exhaust systems fitted. The air compression side of the gas turbines (compression and power generation) are periodically washed with a dilute detergent solution to remove debris.

9.4. Management of Change

Management of Change (MOC) requests will be registered in the Shell FSR 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.

10. Potential Environmental Impacts

10.1. Emissions to Air

Air dispersion modelling was carried out for the operation of the Shell Penguins FPSO using the proprietary Atmospheric Dispersion Modelling Software package (ADMS 6). The main objective of the study (Ref 15) was to determine the potential environmental impact of emissions from the FPSO by comparing the predicted atmospheric concentrations of nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and carbon monoxide (CO) to onshore air quality standards. It should be noted that there are no applicable air quality standards for the offshore UKCS.

The study focussed on the impacts of the FPSO's combustion equipment; namely, the three gas turbine generators (GTGs), the HP compressor (GTC), the IGG, and LP and HP flares. These combustion plant are expected to be the dominant sources of atmospheric emissions on the FPSO. It is anticipated that following the commissioning period, the diesel engines associated with the firewater pumps and emergency generators will only be used in emergencies and furthermore, will normally operate for less than 500 hours per annum and were excluded from the scope of this study. Four operational scenarios were considered when conducting the air dispersion modelling:

- Scenario 1: Normal Operations – max fuel use case. 2 GTGs operating on fuel gas at 100% load, HP compressor operating at 100% load, and the IGG operating at maximum capacity.
- Scenario 2: Normal operations – max fuel use case, with emergency flaring. 2 GTGs operating on fuel gas at 100% load, HP and LP flares operating on an emergency blowdown case, and the IGG operating at maximum capacity.
- Scenario 3: Upset conditions with emergency flaring. 2 GTGs operating on gas oil/diesel at 100% load, HP and LP flares operating on a full flow relief case, and the IGG operating at maximum capacity.
- Scenario 4: Normal operations – realistic case. 2 GTGs operating on fuel gas (one at 50% load and the other at 30% load), HP compressor operating at 100% load and the IGG operating at maximum capacity.

Modelling was carried out to predict the Process Contribution (PC) to the concentrations of each pollutant from the FPSO combustion equipment. The model output was calculated on a 40 km x 40 km grid in the proximity of the FPSO and included the nearby Magnus Oil facility and four points along the UK/Norway median line to estimate the transboundary impact of emissions from the FPSO.

Overall, there were no predicted exceedances of any of the relevant Air Quality Standards for the pollutants of concern, for any of the modelled scenarios at any location. For pollutant concentrations that were not screened out based on their Process Contribution (PC) values, all were deemed insignificant as the corresponding Predicted Environmental Concentration (PEC) was less than 70% of the relevant long term environmental standard. Furthermore, with the prevailing wind direction being broadly parallel to the median line and the relatively low pollutant concentrations that have been estimated from conservative the modelling scenarios, the expected transboundary impacts from the Penguins FPSO is likely to be negligible.

Flaring events and the use of the combustion plant operating on diesel will be minimised, with an overall focus on energy efficiency.

10.2. Water and Discharge Use

The main discharge to water from use of the turbines is from the washing of the turbine blades. There will be no significant discharges to the sea, the washings being routed to the hazardous drains and therefore limited potential impacts arising from the operation of the turbines. The use of HEPA filters will reduce the frequency of water washing of the turbines and therefore shutdowns.

10.3. Waste Management

Liquid and solid waste (including waste arising from the maintenance regime) will be generated from the operation of the turbines and sent to shore for safe recovery, or where this is not possible, disposal. All materials sent ashore as waste will be subject to the duty of care regulations. There will be no significant potential impacts associated with waste disposal.

11. Conclusions

The power requirements for the Penguins FPSO have been strategically evaluated during the Penguins Redevelopment Project. Gas turbine generators with dual fuel capability provide main electrical power to the facility and a gas - fired power turbine drives the HP compressor. All turbines are provided with state-of-the-art dry low-emission (DLE) control systems to reduce environmental discharges of NOx, SOx, 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 (i.e., Titan 130 and Taurus 70 turbines) balances emissions, efficiency, availability, reliability, and capital cost and as such, it represents the Best Available Technique to provide the Penguins 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 B, and it is considered that this equipment configuration represents the Best Available Technique for reduction of emissions from the Penguins FPSO, as defined in the BAT Reference Document (Ref 1), and offers Shell every opportunity to apply the best environmental practices throughout the lifetime of the Penguins field.

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12. EMERGENCY DIESEL GENERATOR PACKAGE -P3NG-4-0302-01-C06-00001

13. SoLoNOx Products- Emissions in Non-SoLoNOx Mode (P3NG-4-0306-01-C17-00017_ 02).

14. Predictive Emissions Monitoring Systems (PEMS) Technical Note, OEUK 2023

15. Penguins Air Quality Impact Assessment Report: 204226C-004-RT-6200-0043. (Genesis, 2024)

Appendix A: Combustion Plant Selection

This appendix provides an overview of process and criteria that was used in the initial selection for the Turbine equipment for the Penguins FPSO during pre-FEED. Several types of equipment were considered and compared.

HP Compressor Power Turbine

The maximum power demand from the HP compressor is predicted to be 14,075 kW in early field life, falling to around 9,433 kW in 2042. Three state-of-the-art models of gas turbine were compared to meet this requirement:

- Titan 130, by Solar
- PGT-25 DLE, by GE
- SGT-600, by Siemens

The Rotating Equipment Type Selection Report (Ref 5) estimated that the Titan 130 gas turbine, although slightly under-powered during peak gas production, is more efficient than the larger PGT-25 DLE and SGT-600 due to a 15% reduction in fuel gas consumption.

Gas turbine driver power demand is based on the production profile shown in Table below. This shows Titan-130 having the lowest average fuel consumption over the full life cycle of the Penguins FPSO.

Table 4   Production profile as a basis for Gas Turbine driver power demand

Date	Production rate (mmscfd)	Compressor Power Demand (MW)	Titan-130 Fuel Consumption (MW)	PGT-25 Fuel Consumption (MW)	SGT-600 Fuel Consumption (MW)
01/01/2020	118	13.1640	41.1221	47.0325	46.3099
01/12/2022	103	14.2010	42.9963	49.8096	49.0928
01/01/2023	98	13.5031	41.6838	47.9403	47.4821
01/03/2024	68	11.7943	39.2288	43.4004	43.5743
01/01/2025	63	11.7943	39.2288	43.4004	43.5743
01/01/2026	55	9.2160	36.3671	36.8736	37.5747
01/01/2027	55	9.1918	36.3389	36.8148	37.5167
01/03/2028	46	8.3567	35.2824	34.8146	35.4777
01/08/2034	44	8.3840	35.3201	34.8791	35.5455
01/12/2039	31	8.3840	35.3201	34.8791	35.5455

Power requirement profiles are summarised in Figure 3, Figure 4 and Figure 5.

Projects & Technology
Upstream Major Projects

PTP/BDA ROTATING EQUIPMENT

Mechanical Drive Gas Turbines

Site Data

Temperature	°C	18
Elevation (± sea level)	m	30

Gas Turbine Power Requirement

Total power required for comp./pump duty	kW	13,100
Additional Margin (If required)		0%
Required Shaft Power	kW	13,100

Derating Adjustments (additional to amb. temp) %

Elevation	0.3
Inlet system (incl air filter)	2.0
Outlet losses	2.0
WHRU in exhaust	0.0
Main gearbox	2.0
Power Reduction (New & Clean)	6.3
Air compressor fouling	2.0
Ageing	3.0
Power Reduction (Degraded)	11.3

Key
Input
Output
Key Output
Meets Requirement

Manufacturer	Model	ISO Performance			Corrected for Amb. Temperature			Available Power		Design Power Margin (Degraded)	
		Power kW	Heat Rate kJ/kWh	Efficiency %	Power kW	Heat Rate kJ/kWh	Efficiency %	New & Clean kW	Degraded kW	Excess Power kW	%
Solar Turbines	Titan 130	15,290	9,940	36.2	15,075	10,002	36.0	14,121	13,367	267	2
GE Oil & Gas	PGT 25	23,266	9,548	37.7	22,797	9,604	37.5	21,354	20,214	7,114	54
Siemens	SGT-600	25,240	10,393	34.6	24,592	10,453	34.4	23,035	21,806	8,706	66

Figure 3 Profile 1 – 13.1 MW compressor shaft power req. 2% excess power margin

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Upstream Major Projects

PTP/BDA ROTATING EQUIPMENT

Mechanical Drive Gas Turbines

Site Data

Temperature	°C	18
Elevation (± sea level)	m	30

Gas Turbine Power Requirement

Total power required for comp./pump duty	kW	14,200
Additional Margin (If required)		0%
Required Shaft Power	kW	14,200

Derating Adjustments (additional to amb. temp) %

Elevation	0.3
Inlet system (incl air filter)	2.0
Outlet losses	2.0
WHRU in exhaust	0.0
Main gearbox	2.0
Power Reduction (New & Clean)	6.3
Air compressor fouling	2.0
Ageing	3.0
Power Reduction (Degraded)	11.3

Key
Input
Output
Key Output
Meets Requirement

Manufacturer	Model	ISO Performance			Corrected for Amb. Temperature			Available Power		Design Power Margin (Degraded)	
		Power kW	Heat Rate kJ/kWh	Efficiency %	Power kW	Heat Rate kJ/kWh	Efficiency %	New & Clean kW	Degraded kW	Excess Power kW	%
Solar Turbines	Titan 130	15,290	9,940	36.2	15,075	10,002	36.0	14,121	13,367	-833	-6
GE Oil & Gas	PGT 25	23,266	9,548	37.7	22,797	9,604	37.5	21,354	20,214	6,014	42
Siemens	SGT-600	25,240	10,393	34.6	24,592	10,453	34.4	23,035	21,806	7,606	54

Figure 4 Profile 2 – 14.2 MW compressor shaft power req. -6% excess power margin

Projects & Technology
Upstream Major Projects

PTP/BDA ROTATING EQUIPMENT

Mechanical Drive Gas Turbines

Site Data

Temperature	°C	18
Elevation (± sea level)	m	30

Gas Turbine Power Requirement

Total power required for comp./pump duty	kW	9,210
Additional Margin (If required)		0%
Required Shaft Power	kW	9,210

Derating Adjustments (additional to amb. temp) %

Elevation	0.3
Inlet system (incl air filter)	2.0
Outlet losses	2.0
WHRU in exhaust	0.0
Main gearbox	2.0
Power Reduction (New & Clean)	6.3
Air compressor fouling	2.0
Ageing	3.0
Power Reduction (Degraded)	11.3

Key

Input
Output
Key Output
Meets Requirement

Manufacturer	Model	ISO Performance			Corrected for Amb. Temperature			Available Power		Design Power Margin (Degraded)	
		Power kW	Heat Rate kJ/kWh	Efficiency %	Power kW	Heat Rate kJ/kWh	Efficiency %	New & Clean kW	Degraded kW	Excess Power kW	%
Solar Turbines	Titan 130	15,290	9,940	36.2	15,075	10,002	36.0	14,121	13,367	4,157	45
GE Oil & Gas	PGT 25	23,266	9,548	37.7	22,797	9,604	37.5	21,354	20,214	11,004	119
Siemens	SGT-600	25,240	10,393	34.6	24,592	10,453	34.4	23,035	21,806	12,596	137

Figure 5 Profile 3 – 9.61 MW compressor shaft power requirements

CO_2 emissions for the 3 compression turbines under consideration are shown below. Titan 130 shows the lowest CO_2 emissions.

PTM/EDES ROTATING EQUIPMENT

Centrifugal Compressor - Operational Cost Calculations

Power Requirement	MD/GEN kW	Power Generation 4,155
Assumed Utilisation		98%
FUEL		
Fuel Gas Cost	USD/MJ	$ 0.0040
Calorific Value	MJ/sm^3	34.2
Efficiency		Power Generation
		Select Turbine: Titan 130
		20%
Annual Energy Requirement	MWh	174,446
Annual Fuel Requirement	sm^3	18,362,726
Annual Operating Cost	USD	$ 2,512,021
CO2 Emissions		
CO2 Emission Factor	kg/sm3	1.86
Gas Turbine	Tonnes/annum	34,192

Power Requirement	MD/GEN kW	Power Generation 4,155
Assumed Utilisation		98%
FUEL		
Fuel Gas Cost	USD/MJ	$ 0.0040
Calorific Value	MJ/sm^3	34.2
Efficiency		Power Generation
		Select Turbine: PGT 25
		17%
Annual Energy Requirement	MWh	210,686
Annual Fuel Requirement	sm^3	22,177,431
Annual Operating Cost	USD	$ 3,033,873
CO2 Emissions		
CO2 Emission Factor	kg/sm3	1.86
Gas Turbine	Tonnes/annum	41,295

Power Requirement	MD/GEN kW	Power Generation 4,155
Assumed Utilisation		98%
FUEL		
Fuel Gas Cost	USD/MJ	$ 0.0040
Calorific Value	MJ/sm^3	34.2
Efficiency		Power Generation
		Select Turbine: SGT-600 (50Hz)
		15%
Annual Energy Requirement	MWh	239,215
Annual Fuel Requirement	sm^3	25,180,532
Annual Operating Cost	USD	$ 3,444,697
CO2 Emissions		
CO2 Emission Factor	kg/sm3	1.86
Gas Turbine	Tonnes/annum	46,887

Figure 6 CO_2 emissions comparisons for the HP Compression Turbines considered.

Figure 8 below shows a comparison of the thermal efficiencies of selectable compressor's gas turbines, and it indicates that Titan 130 compares favourably to PGT-25 and SGT-600 in terms of thermal efficiency and fuel consumption (lower fuel consumption for Titan 130 compared to higher power GTs like the GE PGT-25 and the Siemens SGT-600) (Ref 5). This is mainly due to the larger machines reduced thermal efficiency at part or reduced loads. As maximum power output equals peak production, this plateau is only a period of 6-9 months, therefore Titan 130 will be feasibly shaft-power constrained for 6-9 months. To compensate, the engine can be overfired.

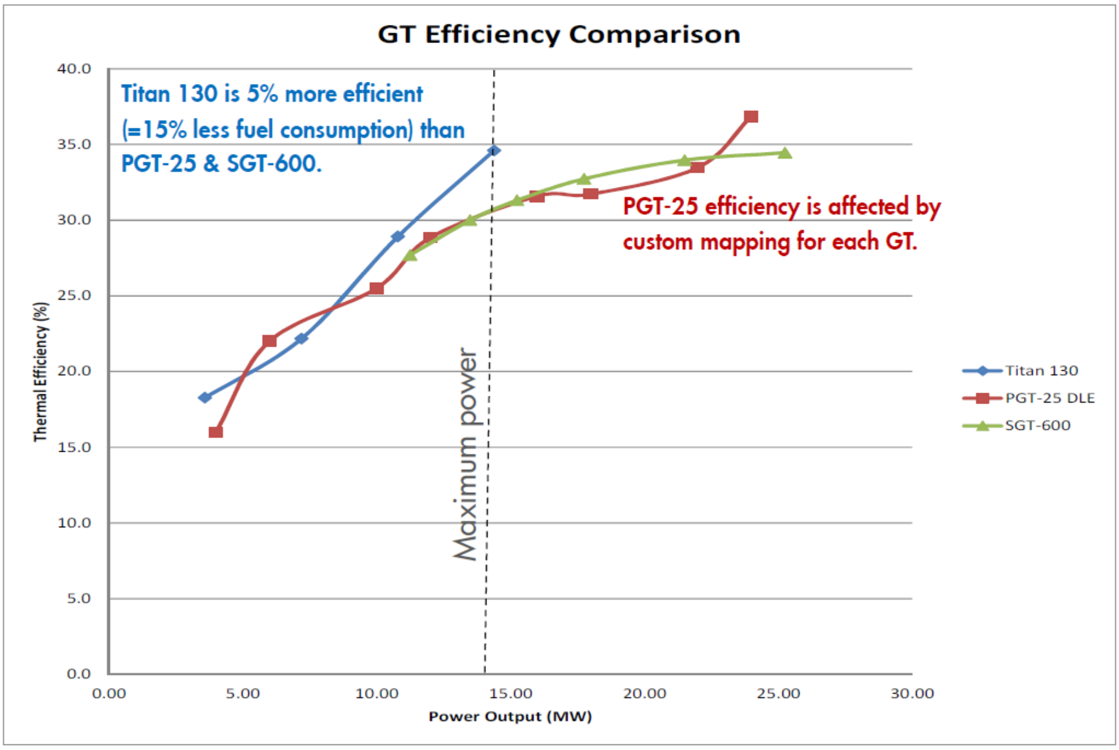

Figure 7 HP Compressor Power Turbines Energy Efficiency Comparison (Ref 6)

Table 5 BAT Scoring Criteria for HP Compressor Power Turbine

	Titan 130, by Solar	PGT-25 DLE, by GE	SGT-600, by Siemens
Technical Feasibility			
Energy Efficiency			
Emissions to Air			
Cost			

Based on the above, the Titan 130 has been selected to provide power to the HP compressor. The turbine is fitted with Solar's SoLoNOx™ Dry Low-Emission (DLE) combustion technology which is optimised to reduce emissions by tightly controlling the combustion temperature inside the turbine. Combustion gases are discharged to the local environment through a stand-alone discharge stack to ensure all components are dispersed. Ports in the exhaust stack are provided to enable sampling of effluent gases with a traversing probe.

Main Electrical Power Supply

The peak electrical power demand for the Penguins FPSO is estimated to be 8.31 MW this is the peak power including offloading. Peak power demand is during peak production, offloading is once every 6 weeks. Maximum normal and offloading off peak is 8.1 MW and will reduce to 7.7 MW during periods when there is no offloading.

Many gas turbines were compared by using a selection tool developed by Shell Projects & Technology (Ref 5). Details are shown in the table below:

Power Generation Drive Gas Turbines

Site Data

Temperature	°C	22
Elevation (± sea level)	m	30

GT Power Requirement (New & Clean)

Site power required	kW	12,000
No. of operating units ("N")		2
Power required per generator	kW	6,000
Minimum design margin (Note 1)	kW	0
Gas turbine power required	kW	6,000

Derating Adjustments (additional to amb. temp) %

Elevation	0.3
API 617 power margin	N/A
Inlet system (incl air filter)	2.0
Outlet losses	2.0
WHRU in exhaust	2.0
Main gearbox	N/A
Power Reduction (New & Clean)	6.3
Air compressor fouling	2.0
Ageing	3.0
Power Reduction (Degraded)	11.3

Compare with New & Clean

Manufacturer	Model	ISO Performance			Corrected for Amb. Temperature			New & Clean	Degraded	
		Power kWe	Heat Rate kJ/kWh	Efficiency %	Power kWe	Heat Rate kJ/kWh	Efficiency %	Power kW	Power kW	
Solar Turbines	Saturn 20	1,210	14,795	24.3	1,157	14,928	24.1	1,083	1,026	
Solar Turbines	Centaur 40	3,515	12,910	27.9	3,345	13,104	27.5	3,133	2,966	
Rolls-Royce / Centrax	501-KB5S	4,101	12,393	29.0	3,812	12,431	29.0	3,571	3,380	
Solar Turbines	Centaur 50	4,600	12,270	29.3	4,364	12,198	29.5	4,088	3,870	
Rolls-Royce / Centrax	501-KB7S	5,518	10,992	32.8	5,208	11,137	32.3	4,878	4,618	
Siemens	SGT-100-1S	5,400	11,613	31.0	5,024	10,449	34.5	4,706	4,455	
Solar Turbines	Taurus 60	5,670	11,430	31.5	5,279	11,971	30.1	4,945	4,681	9,362
Solar Turbines	Taurus 65	6,300	10,945	32.9	5,871	11,142	32.3	5,500	5,206	
Rolls-Royce / Centrax	501-KH-5	6,750	8,971	40.1	6,603	8,949	40.2	6,185	5,855	
Siemens	SGT-200	6,750	11,418	31.5	6,252	11,784	30.5	5,856	5,544	
Solar Turbines	Taurus 70	7,965	10,505	34.3	8,946	10,611	33.9	8,379	7,932	15,864
Siemens	SGT-300	7,900	11,773	30.6	7,356	12,116	29.7	6,890	6,522	
Solar Turbines	Mars 90	9,450	11,300	31.9	8,891	11,453	31.4	8,328	7,883	15,767
MAN Turbo	THM 1304-10	10,080	12,380	29.1	9,500	12,076	29.8	8,898	8,423	

Figure 8 Power Generation Drive Gas Turbines – options considered.

Ultimately, the Taurus 70 turbine, by Solar, was selected to power the main generators in a 3 x 50% configuration. Normally two machines are running with the load shared. One machine is normally on cold stand-by. Running hours are shared across the machines and there may be some situations, like change-over, when all three machines run together for a short period of time.

	MW
PEAK NORMAL & OFFLOADING LOAD	8.31
MAX. NORMAL & OFFLOADING RUNNING PLANT LOAD	8.13
PEAK NORMAL LOAD	8.04

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PTP/BDA ROTATING EQUIPMENT

Power Generation Drive Gas Turbines

Site Data

Temperature	°C	18
Elevation (± sea level)	m	30

GT Power Requirement

Total site electrical power required	kW	8,310
No. of operating units ("N")		2
Power required per generator	kW	4,155

Derating Adjustments (additional to amb. temp) %

Elevation	0.3
Inlet system (incl air filter)	2.0
Outlet losses	2.0
WHRU in exhaust	2.0
Power Reduction (New & Clean)	6.3
Air compressor fouling	2.0
Ageing	3.0
Power Reduction (Degraded)	11.3

Key

Input
Output
Key Output
Meets Requirement

Manufacturer	Model	ISO Performance			Corrected for Amb. Temperature			Available Power (per turbine)		Design Power Margin (Degraded)			
		Power kWe	Heat Rate kJ/kWh	Efficiency %	Power kWe	Heat Rate kJ/kWh	Efficiency %	New & Clean kW	Degraded kW	Per Turbine kW	Per Turbine %	Total Spinning Reserve kW	Total Spinning Reserve %
Siemens	SGT-200	6,750	11,418	31.5	6,577	11,441	31.5	6,160	5,832	1,677	40	3,353	40
Solar Turbines	Taurus 70	7,965	10,505	34.3	7,768	10,546	34.1	7,276	6,888	2,733	66	5,466	66

Figure 9 Selection and spinning reserve operating in N&1 mode.

Operating at a reduced 7.7 MW the Taurus 70 is capable to produce 7.9 MW when the engine is new and clean, and the air temperature is 15°C < (categorised as ISO performance in the selection tool). Therefore, an N&2 mode post peak production, during non-offloading periods and not starting any large drives is feasible and aspirational.

Comparing the two power generation turbines, CO_2 emissions are lower with a Taurus 70 vs. an SGT200. The Taurus 70 is still more thermal efficient at low loads vs the SGT200, therefore is a feasible selection. The comparison between those two options is shown in Figure 10 below. Note: Not considering the alternative option the SGT200 is not dual fuel DLE.

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PTM/EDES ROTATING EQUIPMENT

Centrifugal Compressor - Operational Cost Calculations

Power Requirement	MD/GEN kW	Power Generation 4,155
Assumed Utilisation		98%
FUEL		
Fuel Gas Cost	USD/MJ	$ 0.0040
Calorific Value	MJ/sm^3	34.2
Efficiency		Power Generation Select Turbine: SGT-200 26%
Annual Energy Requirement	MWh	138,285
Annual Fuel Requirement	sm^3	14,556,288
Annual Operating Cost	USD	$ 1,991,300
CO2 Emissions		
CO2 Emission Factor	kg/sm3	1.86
Gas Turbine	Tonnes/annum	27,104

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PTM/EDES ROTATING EQUIPMENT

Centrifugal Compressor - Operational Cost Calculations

Power Requirement	MD/GEN kW	Power Generation 4,155
Assumed Utilisation		98%
FUEL		
Fuel Gas Cost	USD/MJ	$ 0.0040
Calorific Value	MJ/sm^3	34.2
Efficiency		Power Generation Select Turbine: Taurus 70 26%
Annual Energy Requirement	MWh	134,937
Annual Fuel Requirement	sm^3	14,203,877
Annual Operating Cost	USD	$ 1,943,090
CO2 Emissions		
CO2 Emission Factor	kg/sm3	1.86
Gas Turbine	Tonnes/annum	26,448

Figure 10 Power Generation Turbines comparison

Table 6 BAT Scoring Criteria for Main Power Generation Turbines

	Taurus 70, by Solar	**Turbine 2**	**Turbine 3**
Technical Feasibility		Only Taurus 70 is suitable for offshore use and is dual fuel DLE, other gas turbines are only single fuel DLE. No other gas turbines were therefore realistically considered due to high efficiency and low emissions of the Solar Taurus 70.	
Energy Efficiency			
Emissions to Air			
Cost			

In summary, the Solar Taurus 70 was selected as the best fit for the duty based on the following:

- Suitable for offshore usage
- Available power margin (capable to operate in degraded condition & (due for planned maintenance) and capable of starting large loads.
- Highest thermal efficiency available.
- Lowest fuel gas & CO_2 emissions compared to other turbines that were considered.
- Low NOx Dual fuel capability (both gas and diesel) <25 ppm (Siemens SGT200 does not have dual fuel low NOx capability),
- Three Taurus 70s turbines would be required for the N+1 configuration in accordance with Shell's DEPs.
- Spinning reserve of 3,572 kw 35% (2 turbines in operation)
- N&1 gives more than 50% excess capacity at the mean maximum site temperature. (Ref 5) of $18^{o}C$. This arrangement allows maintenance of a single turbine in operation.

Appendix B: Applicability of BAT Conclusions

In order to improve the general environmental performance of the combustion of gaseous and/or liquid fuels on offshore platforms, BAT is to use one or a combination of the techniques given below (Ref 1). The techniques described in the tables below have been evaluated for the Penguins Project to aid the equipment selection.

Table 7 BAT 52 Techniques to Improve Environmental Performance (Ref 1)

Techniques	Description	Penguins Applicability
Process optimisation	Optimise the process in order to minimise the mechanical power requirements	See Section 4
Control pressure losses	Optimise and maintain inlet and exhaust systems in a way that keeps the pressure losses as low as possible	See Section 6.4
Load control	Operate multiple generator or compressor sets at load points which minimise emissions	See Section 5.2
Minimise the 'spinning reserve'	When running with spinning reserve for operational reliability reasons, the number of additional turbines is minimised, except in exceptional circumstances	
Fuel choice	Provide a fuel gas supply from a point in the topside oil and gas process which offers a minimum range of fuel gas combustion parameters, e.g., calorific value, and minimum concentrations of sulphurous compounds to minimise SO_2 formation. For liquid distillate fuels, preference is given to low-sulphur fuels	See Section 6.
Injection timing	Optimise injection timing in engines	N/A to Penguins
Heat recovery	Utilisation of gas turbine/engine exhaust heat for platform heating purposes	See Section 7.1
Power integration of multiple gas fields / oilfields	Use of a central power source to supply a number of participating platforms located at different gas fields / oilfields	See Section 1

Table 8 BAT techniques to improve the environmental performance offshore (Ref 1)

Techniques to improve the environmental performance of combustion plants used on offshore platforms	Penguins Applicability
Selecting turbines or engines which can achieve both a high thermal efficiency and a low emissions spectrum;	See Section 4
Using dual fuel turbines only where operationally necessary;	See Section 5.1
Minimising the spinning reserve;	See Section 4
Providing a fuel gas supply from a point in the topside oil and gas process which offers a minimum range of fuel gas combustion parameters, e.g., calorific value;	See Section 6.2
Providing a fuel gas supply from a point in the topside oil and gas process which offers minimum concentrations of sulphurous compounds, to minimise SO_2 formation, appropriately addressing the safety issue that may be linked to the use of ultra-low-sulphur diesel in Europe due to biofuel (FAME) addition. When using liquid distillate fuels, preference should be given to low-Sulphur types, where the safety and operational consequences are well understood and manageable;	See Section 6.2 and 6.3
Operating multiple generator or compressor sets at load points which minimize pollution;	See Section 5
Optimising the maintenance and refurbishment programmes;	See section 9.3
Optimising and maintaining inlet and exhaust systems in a way that keeps the pressure losses as low as possible;	See Section 9.3.1
Optimising the process in order to minimise the mechanical power requirements and pollution;	See Section 4
Utilising the gas turbine exhaust heat for platform heating purposes where there is a suitable and consistent heat demand and subject to weight and space constraints.	See Section 7.1

Table 9 BAT techniques to prevent/reduce NO_x and CO combustion emissions (Ref 1)

Technique	Achieved Environmental Benefits	Environmental performance and operational data	Penguins Applicability
Direct Steam Injection	Increased efficiency	Limited operational experience	N/A to Penguins
Direct Water Injection	Reduction of NO_x	N/A	N/A to Penguins
Advanced Control System	Reduction of NO_x and CO, and energy efficiency increase	High operational experience	See Section 6
PEMS	Better monitoring. Reduction of NO_x	High operational experience	See Section 6.1
Cheng steam injection cycle	NO_x reduction and efficiency increase	N/A	N/A to Penguins
Dry low-NO_x burners (DLN)	NO_x reduction	NO_x reduction	See Section 5.1, 5.2 and 6.4
Lean-burn concept	Reduction of NO_x	Reduction of NO_x	N/A to Penguins
Selective catalytic reduction (SCR)	Reduction of NO_x	Reduction of NO_x	N/A to Penguins
Oxidation catalysts	Reduction (conversion) of CO into CO_2	Reduction (conversion) of CO into CO_2	N/A to Penguins
Combustion optimisation	Reduction of NO_x and CO emissions	Reduction of NO_x and CO emissions	See Section 5.1, 5.2 and 6.4

Table 10 BAT Techniques considered to improve Energy Efficiency

BAT Techniques to Improve Energy Efficiency	Penguins Applicability
Optimisation of the process in order to	See section 5.1 and 7.1

BAT Techniques to Improve Energy Efficiency	Penguins Applicability
minimise the energy consumption and the mechanical requirements/ optimisation of energy-consuming equipment;	
Using variable speed drives for large rotating equipment if loads are variable;	See Section 7
Optimising line sizes to reduce pressure drops, using expanders and hydraulic pumps to utilise pressure drops instead of throttling;	See Section 7
Optimising equipment sizing to avoid recycling and part-load operation;	See Section 7
Optimising and maintaining inlet and exhaust systems in a way that keeps the pressure losses as low as practically possible;	See Section 6.4
Utilising the gas turbine exhaust heat for platform heating purposes;	See Section 7.1
Considering the lifetime of field production profiles and hence the energy demand which may vary significantly over the 20- to 40-year lifetime of a typical field; this has a significant impact on the loading and machine selection and hence energy efficiency;	See Section 7
Cogeneration of heat and power (CHP)/ waste heat recovery;	See Section 7
Power integration of multiple fields or platforms - use of a central power source to several participating platforms located at different gas fields / oilfields.	See Section 1

Table 11 General BAT Conclusions

No.	General BAT Conclusions – BREF Section 10.1 (Ref 1)	Penguins Applicability
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.	See Section 6.
Monitoring		
BAT 2, 3	Monitoring - Efficiency, and key process parameters to be monitored.	

No.	General BAT Conclusions – BREF Section 10.1 (Ref 1)	Penguins Applicability
BAT 4	Monitoring - 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 (Emissions monitoring plan-204226C-004-RT-6200-0039-2) and Section 7.2
General Environmental and Combustion Performance		
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.	See Section 6
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 for Penguins
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 4 and Section 6.
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 6
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, which includes BAT 10 for the elements covered in BAT 10.	See Section 6
BAT 11	BAT is to appropriately monitor emissions to air and/or to water during OTNOC.	

No.	General BAT Conclusions – BREF Section 10.1 (Ref 1)	Penguins Applicability
Energy Efficiency		
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 relevant items in Table 8 and Table 9.
Water usage and emissions to water		
BAT 13	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 10.2
BAT 14	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.	
Waste Management		
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 10.2