Shell Penguins – Best Available Techniques (BAT) Assessment

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Penguins BAT Assessment for Combustion Plant

March 2024

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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.

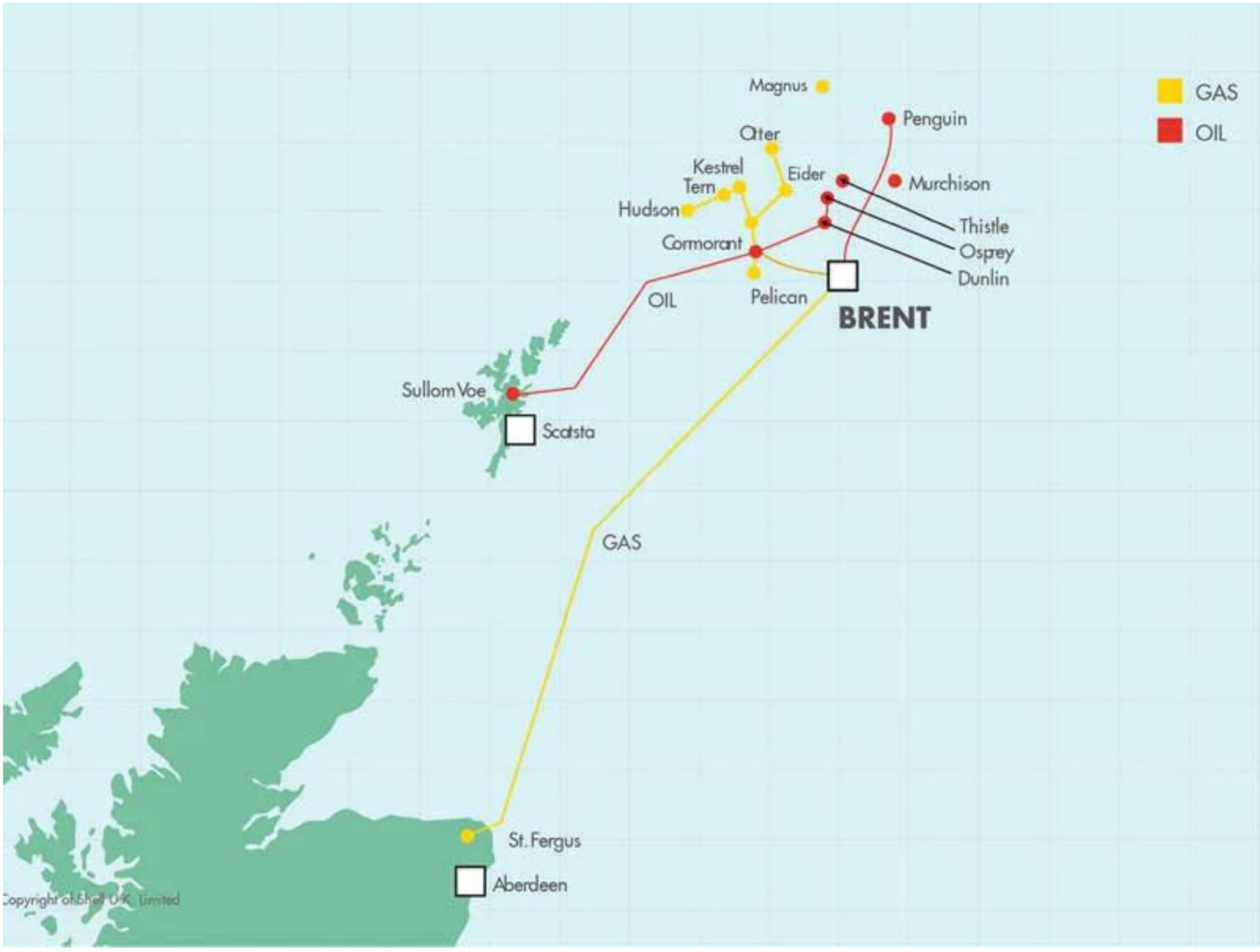

Figure 1 Penguins Field Location Map

Fluids are produced via a host floating, production, storage and offloading (FPSO) vessel from nine existing wells and eight 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.

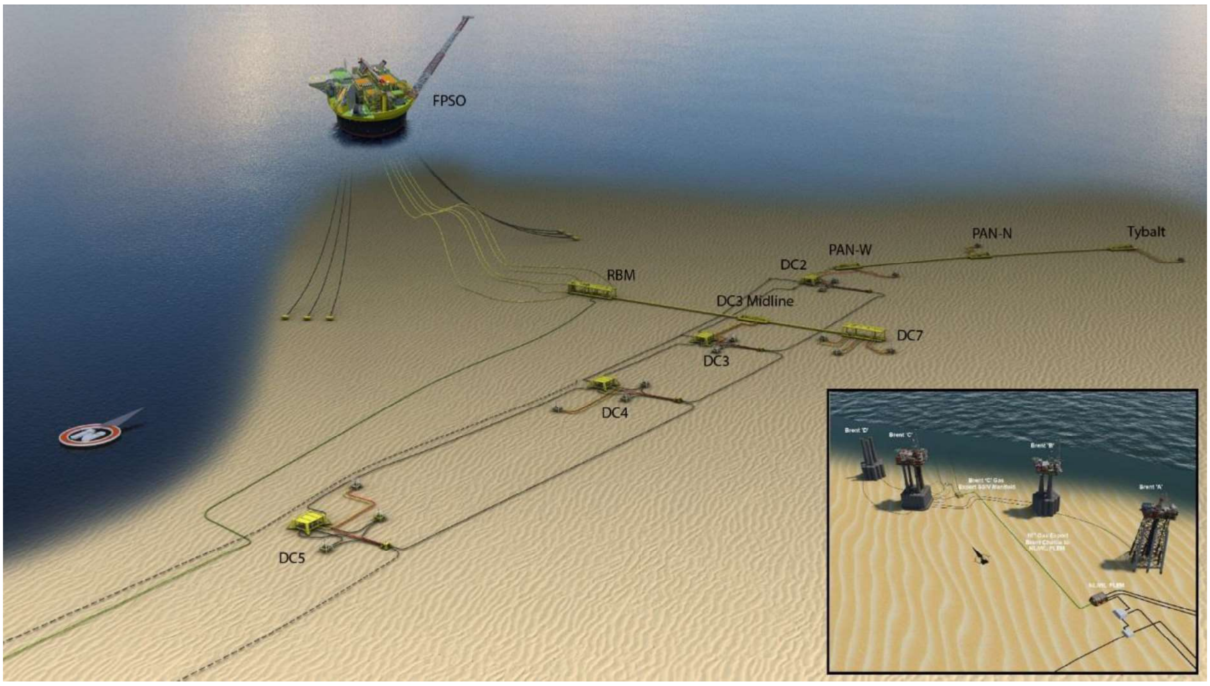

Figure 2 Penguins Redevelopment Field Schematic (not to scale)

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 load shared. 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$_x$™ 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 SO2 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 Vapour Recovery Unit (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 electrical firewater pumps (FWPs) which will be ran at 100% load. 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.

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, as part of the Penguins Redevelopment Project Environmental Statement. The change in location of the FPSO (7.25 km Northwest of the original location) is unlikely to impact air quality-of the modelling due to their localised impacts.

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). They 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.

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. Annex I of the IED states the general aggregation rules for all activities and is 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 II of the IED.

As the combined thermal input of the main combustion plant (3 Gas Turbine Generators and HP Gas Turbine Compressor (GTC)), 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 emissions limits that are applicable for these turbines. 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 (UK Secretary of State, 2018) 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 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. As an aid to this process an offshore specific guidance note was published [OPRED, “Offshore Combustion Installations (PPC) LCP BREF - BATc and IED Article 15(4) Derogation. Guidance notes for the offshore oil and gas industry,” 2020.] though it should be noted that this was written against the earlier 2001 Regulations.

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 (SO2), and other compounds containing sulphur;
- Carbon monoxide (CO);
- Methane (CH4) 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 NOx, in addition to considering the energy performance of main combustion equipment on the installation in line with the offshore guidance. This document considers the impact of NOx, CO and SOx emissions from 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 25ppm.
- Fuel Quality
- Cost – lowest cost.

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. 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 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. Combustion Plant

The combustion plant on the FPSO is listed in Table 1.

Table 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*	*8.6* (3)	23.926(3)	36% (1)	Approx. 8760 hours
Gas Turbine Generator, EG 8001B Make: Solar Turbines Model: Taurus 70-10301S	*Fuel gas with diesel back-up*	*8.6*(3)	23.926(2)	36% (1)	Approx. 8760 hours
Gas Turbine Generator, EG 8001C Make: Solar Turbines Model: Taurus 70-10301S	*Fuel gas with diesel back-up*	*8.6*(3)	23.926(2)	36% (1)	Stand-by
HP Compressor power turbine, KG-2601 Make: Solar Turbines Model: Titan 130-20502S	*Fuel gas*	*15.1*(4)	41.920(3)	36.0% (Shell, 2018)	Approx. 8760 hours
Emergency diesel generator, A-8401 Make: MTU Model: 16V4000 P833A	*Diesel*	*1.94*(3)	5.8	33.4%	150 hours for testing and start-up
Firewater pump diesel generator, A-7101A Make: MTU Model: 16V4000 P83 3B	*Diesel*	*2.464*	5.8	36.8% (Shell, 2018) & (Shell, 2018)	56 hours for testing
Firewater pump diesel generator, A-7101B Make: MTU Model: 16V4000 P83 3B	*Diesel*	*2.464*	5.8	36.8% (Shell, 2018) & (Shell, 2018)	56 hours for testing
Firewater pump diesel generator, A-7101C Make: MTU Model: 16V4000 P83 3B	*Diesel*	*2.464*	5.8	36.8% (Shell, 2018) & (Shell, 2018)	56 hours for testing
Inert Gas Generator, A-6402 Make: Wärtsillä Moss AS Model: Moss Inert Gas Generator	*Diesel*	*Not applicable*	2.5	Not applicable (Shell, 2018)	1500 hours

(1) Penguins Redevelopment Project. (2018). Turbine Data Sheet. P3NG-4-0306-01- C08-00001_01.

(2) Shell. (2018). Emergency Diesel Generator Package – Mechanical Data Sheets. P3NG-4-0302-01-C08-00001_01.

(3) PRD-PT-GEN-00-E-PX-4814-00156 – GTG and EG POPM

(4) PRD-PT-GEN-00-E-PX-4814-00003 – HP Compressor POPM

5.1. Main Power Generation

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 will be carried out weekly in early production. Maximum normal and offloading off peak is 8.1 MW and will reduce to 7.7 MW during periods when there is no offloading.

The 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. At low power load (below 50%) turbine controls prioritise a high exhaust gas temperature to ensure that there is enough heat recovery at the Waste Heat Recovery Units (WHRUs) to avoid process upsets. At these times atmospheric emissions of pollutants are higher. Whenever fuel gas is unavailable (i.e., during initial start-up or fuel gas system upset) each gas turbine can be driven by liquid fuel (diesel) to enable start-up or to prevent unplanned shut-down of the Penguins FPSO.

Combustion gases 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

The maximum power demand from the HP compressor is predicted to be 15,100 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 are:

- 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. One of the firewater pump engines can also be used as a black- start electrical power generator. Each engine is provided with a stand-alone discharge stack.

5.1. 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). For NO_x, CO and UHCs the discharge concentrations can be mitigated by design and operation of the combustion equipment. For SO_x, the discharge concentrations can be mitigated by reducing the concentration of any sulphur contained in the fuel.

Consideration of the mechanisms of nitric oxide formation shows that the design of combustion equipment to reduce its formation by the thermal route involves limiting the overall temperature and residence time, and minimising the formation of hot spots, by optimising air and fuel mixing. (EU, 2017)

Improving the thermal efficiency by operating at higher temperatures, however, tends to increase nitric oxide concentrations, although mass releases may be reduced because of increased energy efficiency. This phenomenon is, however, very plant specific. Normally the NO_X emissions decrease with load due to a decrease in flame temperature. However, for certain dry low-NO_X systems, the emissions of NO_X can be higher when operating in part load mode. It is also worth noting that CO emissions at low loads may rise exponentially in many cases. (EU, 2017)

6.1. 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 (up to 4260 kg/hr).
- Primary fuel supply to GTGs (up to 3016 kg/hr during offloading).
- 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 consumption is accurately metered, and turbine systems can determine the fuel characteristics to achieve optimal control of combustion. Solar's SoLoNOx™ dry low-emission combustion system controls are configured to prioritise low emissions.

Fuel gas composition is expected to be stable, but some changes can be expected during the life of the development.

Table 2 Fuel Gas composition

Component	Mole percent
Methane	72.200
Ethane	13.200
Propane	8.300

Carbon Dioxide	2.500
n-Butane	1.900
Nitrogen	0.800
i-Butane	1.900
i-Pentane	0.200
n-Pentane	0.200
C6+	0.000
Water Vapour	0.000
Hydrogen Sulphide	0.000003530

6.2. Diesel

Low sulphur diesel conforming to DMA ISO 8217, with a maximum sulphur concentration of 0.1%, 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)

Diesel fuel is also used as a back-up fuel source for gas turbines infrequent events where enough super-heated 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., gas turbine), is accurately metered.

6.3. 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.

Facilities are provided to sample exhaust stack discharges from all turbines on the Penguins FPSO. Routine sampling and analysis of exhaust gases will be performed by an independent third-party, allowing Shell to develop an accurate picture of turbine emissions over time for the whole operating range of the machines.

Atmospheric emissions will be higher when the Taurus 70-10301S 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 (Solar, 2018). Liquid fuel is provided as a back-up and is only expected to be used for short periods of time 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.

6.4. 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 %).

7. Energy Efficiency

The Penguins FPSO is a new facility and has been engineered to prioritise energy efficiency through the lifetime of the project (20 years). 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.

Most of the heat duty for process equipment is met by heat recovery from turbine exhaust gases. The maximum heat recovery is approximately 15.6 MW which is used to supply heating medium to heat consumers.

The efficiency of the turbines themselves is only one of the factors of the total energy efficiency of the offshore installation. To make energy production on the platforms more efficient, many other factors have been considered, as detailed in Table 9 in the Appendix B.

7.1. Waste Heat Recovery Unit

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.

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 as this may be indicative of pending failure or increased emissions. Poorly performing equipment will be shut down and repaired at the next available opportunity.

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 GT's includes the SCE related tasks, inclusive of tracking disc run hours, and borescope inspections.

Gas turbines are normally sent for overhaul based upon OEM recommended run hours, typically 30,000 hrs. for Solar, with an option to extend out to 40,000.

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.

9.4. 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 interdisciplinary 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 5). The study carried out detailed modelling of the local NO_x and SO_x atmospheric dispersion around Penguins FPSO to assess the impacts on air quality (Shell, 2017). The study focussed on the impacts of the FPSO's combustion equipment; namely, the three gas turbine generators and the HP compressor, based on assumptions during pre-FEED using conservative scenarios to estimate impacts in a 'worst-case'. Three operational scenarios were considered when conducting the air dispersion modelling:

- Normal operations – when the combustion equipment will be run on fuel gas ;
- Normal operations operating on fuel gas in addition to emergency flaring;
- Upset conditions – this scenario was deemed as the worst case scenario for the emissions to the air, when the gas turbine generators are running on gas oil/diesel fuel, with emergency flaring;

Due to the remote location of the FPSO unit, there are no specific human receptors within 10 km of the FPSO and therefore discrete receptors were not included within the modelling exercise. In order to ascertain the maximum potential impacts off-site, a grid of receptors measuring 20 km by 20 km centred on the FPSO unit site (i.e., a 10 km radius) was used to assess the worst-case impacts at all potential sensitive human receptors in the vicinity of the Penguin FPSO unit location.

For all of the operational scenarios, including the upset conditions scenario (considered to be 'worst case' and highly unlikely), concentrations for the pollutants examined were lower than the relevant air quality standards associated with the considered compounds. Hence, the impact of combustion emissions on the environment around the Penguins FPSO was considered not significant. The model is being revisited by Shell to align with the commissioning and operational philosophy of the FPSO and to validate that the conservative pre-FEED assumptions are applicable, i.e. that the limits in the air quality standards have not been exceeded.

In line with industry best practice, 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 (as indicated within Appendix A) 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 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 (EU, 2017), and offers Shell every opportunity to apply the best environmental practices throughout the lifetime of the Penguins field.

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PRD-PT-GEN-00-E-PX-4814-00156 – GTG and EG POPM

PRD-PT-GEN-00-E-PX-4814-00003 – HP Compressoer POPM

Appendix A: Combustion Plant Selection

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 (Shell UK, 2015) 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 3 below. This shows Titan-130 having the lowest fuel consumption.

Table 3 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.

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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	Heat Rate	Efficiency	Power	Heat Rate	Efficiency	New & Clean	Degraded	Excess Power	
		kW	kJ/kWh	%	kW	kJ/kWh	%	kW	kW	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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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	Heat Rate	Efficiency	Power	Heat Rate	Efficiency	New & Clean	Degraded	Excess Power	
		kW	kJ/kWh	%	kW	kJ/kWh	%	kW	kW	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	Heat Rate	Efficiency	Power	Heat Rate	Efficiency	New & Clean	Degraded	Excess Power	
		kW	kJ/kWh	%	kW	kJ/kWh	%	kW	kW	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) (Shell

UK, 2015). 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.

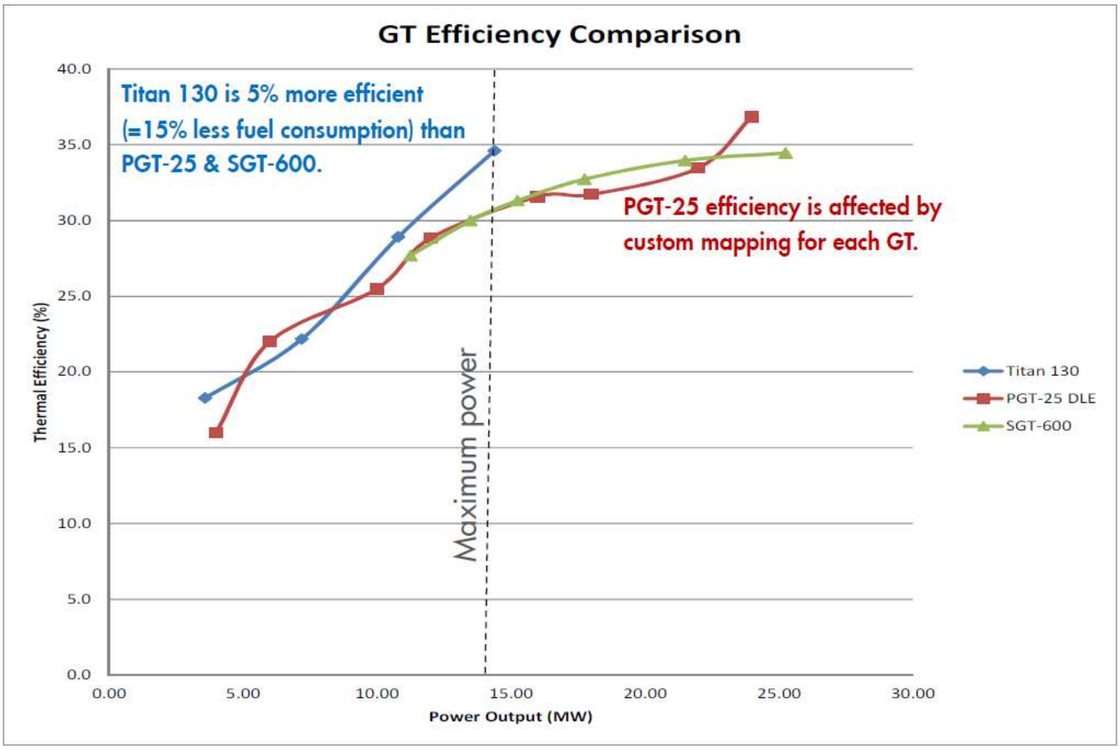

Figure 7 HP Compressor Power Turbines Energy Efficiency Comparison (Shell UK, 2015)

Table 4 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 (Shell UK, 2015). 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	Heat Rate	Efficiency	Power	Heat Rate	Efficiency	New & Clean	Degraded	Per Turbine		Total Spinning Reserve	
		kWe	kJ/kWh	%	kWe	kJ/kWh	%	kW	kW	kW	%	kW	%
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 15ºC < (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	

Projects & Technology
Upstream Major Projects

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 5 BAT Scoring Criteria for Main Power Generation Turbines

<table>
<tr><th></th><th>Taurus 70, by Solar</th><th>Turbine 2</th><th>Turbine 3</th></tr>
<tr><td>Technical Feasibility</td><td></td><td colspan="2" rowspan="4">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 high efficiency and low emissions of the Solar Taurus 70.</td></tr>
<tr><td>Energy Efficiency</td><td></td></tr>
<tr><td>Emissions to Air</td><td></td></tr>
<tr><td>Cost</td><td></td></tr>
</table>

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) <25ppm (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 3,572kw 35% (2 turbines in operation)
- N&1 gives more than 50% excess capacity at the mean maximum site temperature. (Shell UK, 2015) of 18oC. 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 (EU, 2017). The techniques described in the tables below have been evaluated for the Penguins Project to aid the equipment selection.

Table 6 BAT 52 Techniques to Improve Environmental Performance (EU, 2017)

Techniques	Description	Penguins Applicability
Process optimisation	Optimise the process in order to minimise the mechanical power requirements	High efficiency gas compressor trains and process equipment have been studied and selected to minimize power demand. Study and selection of the GT driver for gas compression was based on minimum fuel gas usage during the expected field life.
Control pressure losses	Optimise and maintain inlet and exhaust systems in a way that keeps the pressure losses as low as possible	HEPA-12 filtration systems will be fitted to all GT drivers. Low pressure drop exhaust systems fitted.
Load control	Operate multiple generator or compressor sets at load points which minimise emissions	Penguins only has single gas compression train. Hence its operation will be determined by the process duty imposed on it. Minimum number of power generation trains will operate provide security of supply.
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 SO2 formation. For liquid distillate fuels, preference is given to low-sulphur fuels	Fuel gas is taken from gas compressor discharge, then treated and heated before being consumed by the GT(s). Fuel gas treatment skid is designed to meet Solar's fuel gas specification (ES-98).
Injection timing	Optimise injection timing in engines	Not applicable to gas turbines
Heat recovery	Utilisation of gas turbine/engine exhaust heat for platform heating purposes	Each GT driver for power generator has been fitted with Waste Heat Recovery system for heating crude oil.

Techniques	Description	Penguins Applicability
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	This was considered but power supply from neighbouring platforms is not possible.

Table 7 BAT techniques to improve the environmental performance offshore (EU, 2017)

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;	1-off Solar Titan 130 DLE was selected for gas compression. 3-off Solar Taurus 70 were selected for power generation. Both are class leading for thermal efficiency and emissions.
Using dual fuel turbines only where operationally necessary;	Dual fuel combustion system was only selected for power generation to ensure security of supply.
Minimising the spinning reserve;	Selection of the GT driver for power generation was based on N+1 criterion during maximum loading.
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;	Fuel gas is taken from gas compressor discharge, then treated and heated before being consumed by the GT(s). Fuel gas treatment skid is designed to meet Solar's fuel gas specification (ES-98).
Providing a fuel gas supply from a point in the topside oil and gas process which offers minimum concentrations of sulphurous compounds, to minimise SO2 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;	Process datasheet shows sulphurous compounds are not expected in the Penguins fuel gas stream which is expected to meet Solar's fuel gas specification (ES-98).
Operating multiple generator or compressor sets at load points which minimize pollution;	Penguins only has single gas compression train hence its operation will be determined by the process duty imposed on it. Minimum number of power generation trains will operate to provide security of supply.

Techniques to improve the environmental performance of combustion plants used on offshore platforms	Penguins Applicability
Optimising the maintenance and refurbishment programmes;	Planned maintenance for single gas compression train. Condition based maintenance for power generation train.
Optimising and maintaining inlet and exhaust systems in a way that keeps the pressure losses as low as possible;	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.
Optimising the process in order to minimise the mechanical power requirements and pollution;	High efficiency gas compressor trains and process equipment have been studied and selected to minimize power demand and minimise pollution.
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.	Each GT driver for power generator has been fitted with Waste Heat Recovery system for heating crude oil.

Table 8 BAT techniques to prevent/reduce NO_X and CO combustion emissions (EU, 2017)

Technique	Achieved Environmental Benefits	Environmental performance and operational data	Penguins Applicability
Direct Steam Injection	Increased efficiency	Limited operational experience	Not applicable to Solar DLEs
Direct Water Injection	Reduction of NO_X	N/A	Not applicable to Solar DLEs
Advanced Control System	Reduction of NO_X and CO, and energy efficiency increase	High operational experience	GT control system has already been engineered the necessary features required for DLE control.
PEMS	Better monitoring. Reduction of NO_X	High operational experience	Generally applicable – RH: but not selected for project. Why?
Cheng steam injection cycle	NO_X reduction and efficiency increase	N/A	Not applicable to Solar DLEs

Technique	Achieved Environmental Benefits	Environmental performance and operational data	Penguins Applicability
Dry low-NOX burners (DLN)	NO_X reduction	NO_X reduction	Applicable to new gas turbines (standard equipment) within the constraints associated with fuel quality variations. The applicability may be limited for existing gas turbines by: availability of a retrofit package (for low-load operation), complexity of the platform organisation and space. Solar's DLE combustion systems have been selected for all Solar turbines on Penguins.
Lean-burn concept	Reduction of NO_X	Reduction of NO_X	Only applicable to new gas-fired engines . Not applicable to Solar DLEs
Selective catalytic reduction (SCR)	Reduction of NO_X	Reduction of NO_X	Not applicable to Solar DLEs
Oxidation catalysts	Reduction (conversion) of CO into CO_2	Reduction (conversion) of CO into CO2	Not applicable to Solar DLEs
Combustion optimisation	Reduction of NOx and CO emissions	Reduction of NO_X and CO emissions	Solar's DLE combustion systems have been selected for all Solar turbines on Penguins.

Table 9 BAT Techniques considered to improve Energy Efficiency

BAT Techniques to Improve Energy Efficiency (EU, 2017)	Penguins Applicability
Optimisation of the process in order to minimise the energy consumption and the mechanical requirements/ optimisation of energy-consuming equipment;	Energy consumption has been minimized by process design and equipment selection.
Using variable speed drives for large rotating equipment if loads are variable;	Variable speed drive has been used on the GT driven compressor set. Variable speed is not available on GT driven generator sets.

BAT Techniques to Improve Energy Efficiency (EU, 2017)	Penguins Applicability
Optimising line sizes to reduce pressure drops, using expanders and hydraulic pumps to utilise pressure drops instead of throttling;	Line sizing has been considered and optimized during Process design.
Optimising equipment sizing to avoid recycling and part-load operation;	Equipment sizing has been considered and optimised during process design.
Optimising and maintaining inlet and exhaust systems in a way that keeps the pressure losses as low as practically possible;	HEPA-12 filtration systems will be fitted to all GT drivers. Low pressure drop exhaust systems fitted.
Utilising the gas turbine exhaust heat for platform heating purposes;	Waste heat recovery has been fitted to the GT generator sets.
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;	High efficiency gas compressor trains and process equipment have been studied and selected to minimize power demand. Study and selection of the GT driver for gas compression was based on minimum fuel gas usage during the expected field life.
Cogeneration of heat and power (CHP)/ waste heat recovery;	Each gas turbine driver for power generator has been fitted with Waste Heat Recovery system for heating crude oil. Increased energy efficiency.
Power integration of multiple fields or platforms - use of a central power source to several participating platforms located at different gas fields / oilfields.	Considered but not feasible with surrounding platforms.

Table 10 General BAT Conclusions

No.	General BAT Conclusions – BREF Section 10.1 (EU, 2017)	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.	Shell's EMS is 14001 certified and adheres to the relevant BAT features. See Section 6.
Monitoring		
BAT 2, 3	Monitoring - Efficiency, and key process parameters to be monitored.	Please refer to the Stack Monitoring Plan as per this PPC Permit Application.
BAT 4	Monitoring - The frequency of monitoring is given in BAT 4 for combustion plants on offshore platforms.	

No.	General BAT Conclusions – BREF Section 10.1 (EU, 2017)	Penguins Applicability
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 relevant items in Table 8 and Table 9.
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.	Not applicable to Solar DLEs.
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 6.5.
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)	Fuel gas composition is accurately metered and turbine systems can determine the fuel characteristics to achieve optimal control of combustions. Fuel gas composition is presented in Table 2.
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.	OTNOC not normally cover offshore not covered in BAT.
BAT 11	BAT is to appropriately monitor emissions to air and/or to water during OTNOC.	
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 7 and Table 8.
Water usage and emissions to water		
BAT 13	In order to reduce the water usage and the volume of contaminated waste water discharge, BAT is to use one or both of the techniques given.	The use of HEPA filters (as indicated within Appendix A) will reduce the frequency of
BAT	In order to prevent the contamination of	

No.	General BAT Conclusions – BREF Section 10.1 (EU, 2017)	Penguins Applicability
14	uncontaminated waste water and to reduce emissions to water, BAT is to segregate waste water streams and to treat them separately, depending on the pollutant content.	water washing of the turbines and therefore shutdowns.
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.	Liquid and solid waste will be generated from the operation of the turbines and sent to shore for safe recovery, or where this is not possible, disposal.