OpenWater Energy Newsletter

January 2022

Decarbonising Floating Oil & Gas Facilities

Part 1 - Floating Production, Storage & Offloading Vessels

1. Introduction

The objective of this newsletter is to discuss the options available to decarbonise a modern, large capacity FPSO. The second part of this paper will be issued soon and will discuss similar options for an FLNG.

A glossary of terms used is included in section 9.

Typical large FPSOs have multiple sources of environmental emissions, both to air and to sea. Technology exists to significantly reduce or eliminate these emissions, however, until recently, few projects have gone beyond the minimum level needed to comply with local regulations. Pressure is now mounting to reduce emissions further for several reasons.

Firstly, there is Environmental, Social, and Governance (ESG) pressure from stakeholders to reduce the environmental impact – both from internal stakeholders (staff) and external stakeholders (host governments, shareholders, media, and the public). Secondly, Financial Institutions are becoming more selective in the projects they finance (due to their own ESG pressure) and are likely to favour those which can show low carbon footprints. Thirdly, the application of Carbon Tax, either imposed externally by local authorities or internally as a project sanction test, will also drive projects towards lower emissions.

For all these reasons, technologies to reduce emissions are growing in importance, and we expect these to be widely applied soon.

2. Baseline

To help illustrate the potential to decarbonise, we have calculated the typical baseline emissions from a large modern FPSO. We have selected a typical generic FPSO for Pre-Salt Brazil as a reference case, with an oil capacity of 150,000 bpd, a gas production capacity of 400 MMscfd, and a water injection capacity of 250,000 bpd. We have illustrated the main sources of emissions from this type of unit in **Figure 1** (see page 7).

We have calculated the total CO_2 equivalent emissions for this Reference FPSO, using GWP to convert hydrocarbon emissions back to CO_2e. We used vendor data for fuel demand and corrected this for gas turbine partial loading. We find total CO_2 equivalent emissions are around 660,000 TPA, at full capacity, which is broken down as shown in **Figure 2** below.

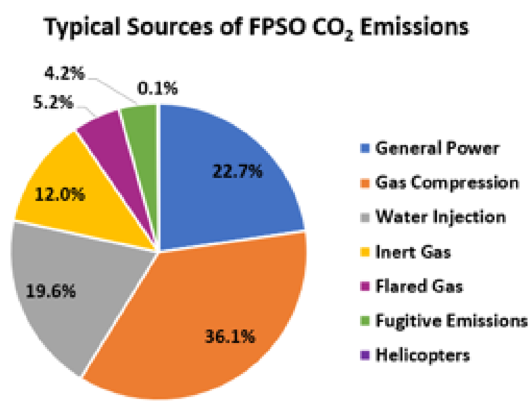


Figure 2

The main emissions come from the gas turbines used for power generation and compressor direct drives. In this case, we have assumed seven LM2500+G4 gas turbines, with four used for power generation and a further three for direct drive of the main gas compressors. The CO_2 in the exhaust gas from these seven machines represents around 80% of the total FPSO annual emissions (the water injection pumps are electric drive). For these calculations we used data published by SINTEF. [Ref 1]

The next largest source is Inert Gas (IG) which is traditionally used as cargo tank blanket gas and is cold vented during the tank filling cycle. Lean IG is composed of Nitrogen and Carbon Dioxide, with a small residual Oxygen content. But after being in contact with crude oil for several days, the IG becomes rich in volatile hydrocarbons [Ref 2, 3] with hydrocarbon levels up to 80% volume being quoted by some, at the end of the loading cycle, and elsewhere in literature as between 30% and 80% volume hydrocarbons [Ref 4]. For this analysis, we have assumed an average of 50% by volume. As the Greenhouse Warming Potential of these hydrocarbons is significantly higher than for CO_2, vented IG can represent between 10% to 15% of the total FPSO CO_2 equivalent emissions, depending on the crude oil volatility and storage tank conditions. (Note – we have not included IG vented from the offloading shuttle tanker as it is being filled).

Gas flaring and venting may contribute between 5% and 10% to the annual emissions if the plant is reliable and has a low frequency of process upsets and trips. Normally only a small flow of purge gas and pilot gas will be burned. But during the periodic process upsets, plant trips and subsequent restarts, or preparation of equipment for maintenance, significant amounts of gas are flared for a short duration. Moreover, flare tips are typically around 98% efficient, so there will be a small amount of methane slip to atmosphere, which is important due to the high GWP of methane.

Finally, we have included emissions from helicopters for the crew transportation to and from the vessel. However, in comparison to the above emissions, these are not significant.

We have also included in this analysis the emissions to sea, mainly from produced water discharges.

3. Pathways to Decarbonise FPSOs

We have grouped the various technology initiatives available to reduce emissions into five broad categories, shown below in ascending order of cost and effort to deploy. These are discussed in more detail in the following section and are illustrated in **Figure 3** (see page 7).

For each, we include an indication of the Technology Readiness Level (TRL) for the application of this technology. This is based on the API 17N [Ref 5] seven-point gate system, where TRL1 is a new conceptual idea and TRL7 is when new equipment has been proven in service for at least 3 years. The TRL shown is our view of the application of the technology to FPSO service, which may differ from wider industry applications.

Category	Technology Options	TRL for FPSO Application
Optimisation	• Improved Efficiency – reduced fuel consumption • Better O&M procedures – reduced flaring • Digitalisation • Optimised Logistics – reduced traffic to/from the FPSO	7 7 7 7
Flare & Vent	• Reduced Fugitive Emissions • Closed flare – eliminate routine flaring • Hydrocarbon Gas Blanketing of Cargo Tanks	7 7 7
Produced Water	• Reinjection, comingled with treated seawater • Polishing Filters	7 7
Fuel Demand	• Combined Cycle Gas Turbines for Power Generation • Renewable Power Import (Floating Wind Turbines) • Power import from shore • Battery Energy Storage System (BESS)	7 4 7 6
Exhaust Gas	• Pre-Combustion CC(U)S - Hydrogen fuel blending • Post-Combustion CC(U)S	3 3

4. Technology Options

4.1 The simplest pathway to reduce emissions is through optimisation of the current facilities, without any major hardware change. The options available include the following.

a) Improved Efficiency. By running the main machines (compressors and pumps) at the highest possible efficiency points, power demand can be reduced, with an equivalent reduction in CO_2 emissions. Examples could be optimising compressor recycle flows or avoiding shared load between two parallel machines (each operating at sub-optimal conditions).

b) Digitalisation. The use of advanced Digital tools and AI can improve plant uptime and reduce the number of process upsets, trips, and restarts, so reducing the amount of gas flared. An Onshore Support Centre manned by Engineers with access to live plant data and advanced AI tools can support the offshore crews to ensure that machinery is running as close to the optimum efficiency points as possible, reducing power consumption and fuel demand, as discussed above.

c) Better Operations & Maintenance procedures. Plant trips and restarts are the major source of gas flaring. Operating procedures can often be optimised to reduce the amount of flaring, such as by better consideration of the timing of the well opening sequence and the compressor restart procedures. Dynamic simulations can be used to test alternative restart scenarios and develop robust procedures to minimise flaring. Similarly, procedures for the preparation of equipment for maintenance can often be optimised to reduce the quantity of gas to be flared or vented, such as by partial depressurisation through the process train before final depressurising to flare.

d) Optimised Logistics. By optimisation of logistics planning for crew, vendor assistance, catering provisions, production chemicals and spare parts, it may be possible to reduce the number of helicopter and supply boat trips needed per year, so reducing emissions (and cost). Digitalisation should also reduce the required number of crew, and the number of visits needed by vendor technicians, so again reducing emissions related to travel.

The above should be considered as routine operations and maintenance management, but it is important to ensure that this basic step is achieved before considering more complex solutions. Projects located in areas having a high Carbon Tax tend to be more advanced in implementing the above type of measures.

We estimate that emissions may be up to 5% higher than the baseline level if the plant is being run with sub-optimal conditions.

4.2 Flare, Vent and Fugitive Emissions

Estimating the quantity of Fugitive Emissions is difficult. An interesting study was published in 2019 which investigated the fugitive emissions from 8 North Sea oil and gas installations and found these to average 36 kg/hr [Ref 6]. Since our Reference Case has topsides around 3 times the size of an average North Sea Platform, we have assumed a value of 108 kg/hr for our Reference FPSO.

Piping flanges, valve stem seals, and instrument tubing joints are all possible sources of small gas leaks to the atmosphere. These may be too small to trigger the gas detection systems, but when accumulated they can be a significant source of fugitive methane emissions. Regular IR camera surveys should be performed to identify and repair any such sources of fugitive emissions. ATEX certified IR cameras are now widely available for this purpose [Ref 7].

A proven solution (TRL7) to routine gas flaring is the 'Closed Flare' design. This uses a high integrity valve or valves (with a bursting disc bypass) and a recycle compressor to return all purge gas, vented process gas and any gas leakage (such as from safety valves and blowdown valves) to the main process system. Only in case of a significant release of gas to flare, above the capacity of the recycle compressor, will the high integrity valve(s) open to release gas to the flare tip. This system has been widely used in Norway for many years [Ref 4] but is less common in other locations.

A proven solution also exists to eliminate routine Inert Gas venting, this being the use of 'hydrocarbon gas blanketing' to replace IG. During offloading operations, a low-pressure gas stream (such as fuel gas or process gas) enters the tanks and is later displaced back to the process during tank filling (via a vapour recovery compressor). The atmospheric discharge of rich IG is therefore eliminated in normal operations. However, for tank cleaning, inspection and maintenance, when manned entry inside a tank may be needed, it is still necessary to use lean IG as part of the 'gas freeing' operation to displace the fuel gas before the tank is ventilated. Similarly, after inspection, the tank would be inerted with lean IG before being filled with process gas. The use of HC gas blanketing is TRL7 and is widely adopted in Norway, where at least 9 FPSOs use this design [Ref 4] but it is less common elsewhere.

The American Bureau of Shipping published a Hydrocarbon Blanket Guide in 2014 to give guidance on the safe design of these systems [Ref 8].

4.3 Reduced Fuel Gas Demand

To reduce the fuel gas demand of the main power generation system, three options are available. Firstly, by increasing the efficiency of the power generation system, so that less fuel gas is required to deliver the same power. The most effective way to do this is to move from the traditional simple cycle gas turbines, with typical peak efficiencies in the range of 35% to 40%, to combined cycle systems which have typical efficiencies between 50% and 60%. Equinor's Johan Castberg FPSO, currently under construction, will be the first major FPSO project to deploy Combined Cycle power generation [Ref 9] and will be followed by Equinor's Bacalhau FPSO for Brazil, and Santos' Barossa FPSO in Australia. However, similar systems have already been installed on some semi-submersible production units, like Snorre and Appomatox, so this is considered as proven technology on floating production units (TRL7). Although the power generation equipment is larger, more costly and more complex, it can reduce fuel gas demand by around 25%.

Some have advocated the use of an Organic Rankine Cycle for waste heat recovery, instead of using steam, but this is less mature and has yet to be implemented at scale.

Secondly, to reduce fuel demand further, power import from an external source is needed – either from shore or from adjacent wind turbines. The shore power option has been applied in Norway, for example on the circular Goliat FPSO, and some FPSOs with drag-chain turrets are thought to be capable of power import. But although the swivel technology for HV power import through a conventional turret is qualified to TRL4, this has not yet been applied on a project at full scale.

Equinor has pioneered offshore floating wind to partly power an offshore facility with the Hywind Tampen project, where the 88 MW of renewable power will feed the Gullfaks and Snorre platforms, meeting about 35% of their annual power demand [Ref 10] from late 2022. Several other projects are considering similar schemes, and with four leading FPSO contractors also investing in wind technology, we can expect to see this technique deployed soon to reduce FPSO emissions.

Finally, another technology available is the use of Battery Energy Storage Systems (BESS). This can provide a virtual 'spinning reserve' without the need to run a spare generator on shared load. Turbine efficiency drops quickly with part load, so sharing the load between multiple machines increases emissions. Using BESS as an alternative standby power source allows the generator(s) to be run closer to full load, and so closer to peak efficiency. Woodside installed the first offshore BESS rated a 1 MWh on the Goodwyn A platform, offshore Australia, in 2019. The objective was to allow the platform to run with three gas turbine generators, instead of four [Ref 11]. Application on an FPSO should be no different to a platform, so we consider this to be mature at TRL6 (but not yet TRL7, since it is less than 3 years in operation).

4.4 Reduced CO_2 in Exhaust Gases

To reduce the CO_2 content of gas turbine exhaust gas streams, Carbon Capture & Storage (CCS) can be used in two configurations; pre-combustion and post-combustion.

4.4.1 Pre-Combustion CCS

As shown in Figure 3, Pre-combustion CCS takes a slipstream of fuel gas through a Hydrogen reformer process and blends the resulting H_2 product back into the main fuel gas stream. The reformer process includes a conventional CO_2 removal step, achieving very high recovery rates of CO_2, which can then be re-injected. Many gas turbines are now able to run reliably with H_2 blended into fuel gas at rates from 10% to 100%, depending on the model. By blending say 30% H_2 into fuel gas, CO_2 emissions from gas turbines will be reduced by a similar amount.

An H_2 reformer unit with an associated CO_2 compressor could be modularised and readily integrated into new FPSO projects. Some process licensors have optimised Blue Hydrogen processes to be more suitable for modular construction, such as the Johnson Matthey LCH™ process. [Ref 12].

4.4.2 Post-Combustion CCS

In comparison, post-combustion CCS suffers from more difficult challenges.

- Lower CO_2 recovery (80% to 90% maximum) [Ref 13]
- Solvent degradation issues from some flue gas components [Ref 14].
- Lower technical maturity and higher project risk

These challenges have slowed the application of post-combustion CCS projects onshore, and even more so for offshore applications. For these reasons, pre-combustion CCS may become more favoured for FPSO applications.

5. Emissions to Sea

5.1 Produced Water

Most FPSOs have a process unit which treats the water separated from the produced oil so that it is within the local regulatory limits for discharge to sea. A typical oil-in-water specification would be <29mg/l oil in water, being the total of suspended and dissolved oil.

A flowrate of 100,000 bpd produced water with 25 mg/l residual oil is equivalent to an annual discharge of 141 tonnes of oil. The quantity of oil discharged can be reduced in three ways.

a) Reinjection of the produced water into the reservoir, along with the water injection stream. For this, the produced water must be treated to prevent any loss of well injectivity.

b) Settling tanks, to hold 'off-specification' produced water and allow it to settle, so lowering the oil content before reprocessing or overboard discharge.

c) Polishing the treated produced water to remove more oil, such as by use of media filters which can reduce oil content to below 10 mg/l (Ref 16).

The addition of polishing units, for example, could achieve a 60% reduction in annual oil discharge on many FPSOs.

5.2 Sea Water Returns

The FPSO cooling water system will discharge heat to the sea, but the maximum discharge temperature is usually closely regulated to minimise the environmental impact. With the increasing use of low sulphate water for reservoir injection, a high salt reject stream is returned to the sea. However, the overall environmental impact in deep ocean conditions is not considered to be significant.

6. Other Emissions

Converted FPSOs may retain the original marine boiler systems to drive the cargo offloading pumps. These are an additional source of CO_2 emissions, albeit with intermittent use. The alternative is to use submerged cargo pumps in each tank driven from a central HPU which is then powered from the main power generation system.

Essential and emergency diesel-powered generators are also sources of CO_2 emissions, but their short-term intermittent use makes this insignificant.

7. Benchmarking

The emission levels for the Reference Case FPSO are calculated as 8.3 kgCO_2e/boe (kg CO_2 equivalent per barrel of oil equivalent) at peak production in early life, rising to around 24.7 kgCO_2e/boe in later field life (since water injection and gas lift power demands are not directly correlated with production rates). On average, the emissions for the Reference Case vessel would be around 16 kgCO_2e/boe over the field life.

These values match well with the figures recently published by Petrobras for their offshore production which show average emission rates of 30 kgCO_2e/boe in 2009, falling to 15.7 kgCO_2e/boe in 2021 and with a target of 10 kgCO_2e/boe for the Buzios field and 9.3 kgCO_2e/boe for Tupi (Ref 17).

We have also benchmarked the Reference Case FPSO with data published by OIES (Ref 15) which shows an average emission intensity of 28 kgCO_2e/boe offshore UK, and 10 kgCO_2e/boe offshore Norway. The Norwegian figures are lower, due to the long history of tighter emission standards and offshore CO_2 taxation there. Again, our Reference Case fits well within this data.

8. Conclusions

The Reference Case FPSO emissions benchmark well with today's standard practice. But a range of proven technologies exist which can reduce our Reference Case FPSO emissions further, summarised in **Figure 4**.

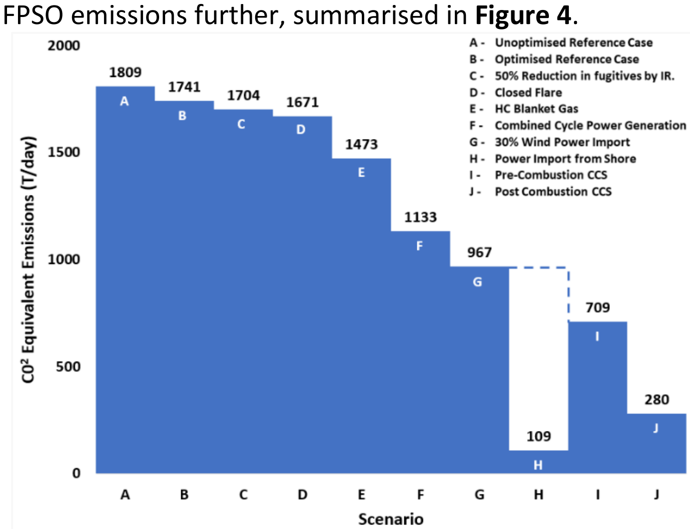


Figure 4 - Decarbonisation Options

From the Reference Case (point A on the chart), measures for optimisation, control of fugitive emissions, and switching to a closed flare all lead to relatively modest reductions in carbon emissions. But implementing the deeper design changes of Hydrocarbon Blanket Gas, Combined Cycle Power Generation, and Floating Windpower import to 30% of the electrical power demand, should reduce the overall carbon emissions to around 4.4 kgCO_2e/boe at peak production, a reduction of around 47%. These solutions all have a low level of technology risk.

To reduce emissions further, power import from shore is the most effective solution, but only if a green power source is available and it is technically feasible to cable this to the FPSO, depending on the distance from shore and water depth.

Alternatively, adding Pre-combustion CCS to deliver 30% Hydrogen blended into the fuel gas is a promising alternative. This would reduce early life emissions to around 3.3 kgCO_2e/boe, a total reduction of around 60%. The Sankey Chart in **Figure 5** (see page 8) shows the emission reductions for this case.

The alternative of Post-combustion CCS may allow emissions reduction to reach over 80%, but again this is not yet mature technology for offshore applications and looks more difficult to implement.

For emissions to sea, produced water reinjection and media filter polishing are both mature technologies that can be readily applied. Polishing can reduce oil discharge by around 60%, and reinjection (where technically possible) can virtually eliminate this.

The optimum choice of emission-reduction technologies for each FPSO will be a project-specific decision, depending on the field location and factors such as the emission intensity needed to secure project finance. The risks of deploying technology that is not yet mature should be balanced with the rewards of lower emissions, to manage project risks.

OpenWater Energy Ltd is pleased to be assisting Clients with these difficult decisions.

9. Glossary

AI	Artificial Intelligence
ATEX	Appareils destinés à être utilisés en Atmosphères EXplosibles
BESS	Battery Energy Storage System
BOE	Barrel of Oil Equivalent
CC(U)S	Carbon Capture, (Utilisation) and Storage
CO_2e	$C0_2$ Equivalent
ESG	Environmental, Social, Governance
FPSO	Floating Production, Storage and Offloading vessel
FLNG	Floating LNG Liquefaction vessel
GWP	Greenhouse Warming Potential
HC	Hydrocarbon
HPU	Hydraulic Power Unit
IG	Inert Gas
IR	Infra-Red
TPA	Tonnes per Annum
TRL	Technology Readiness Level, per API 17N

Figure 1

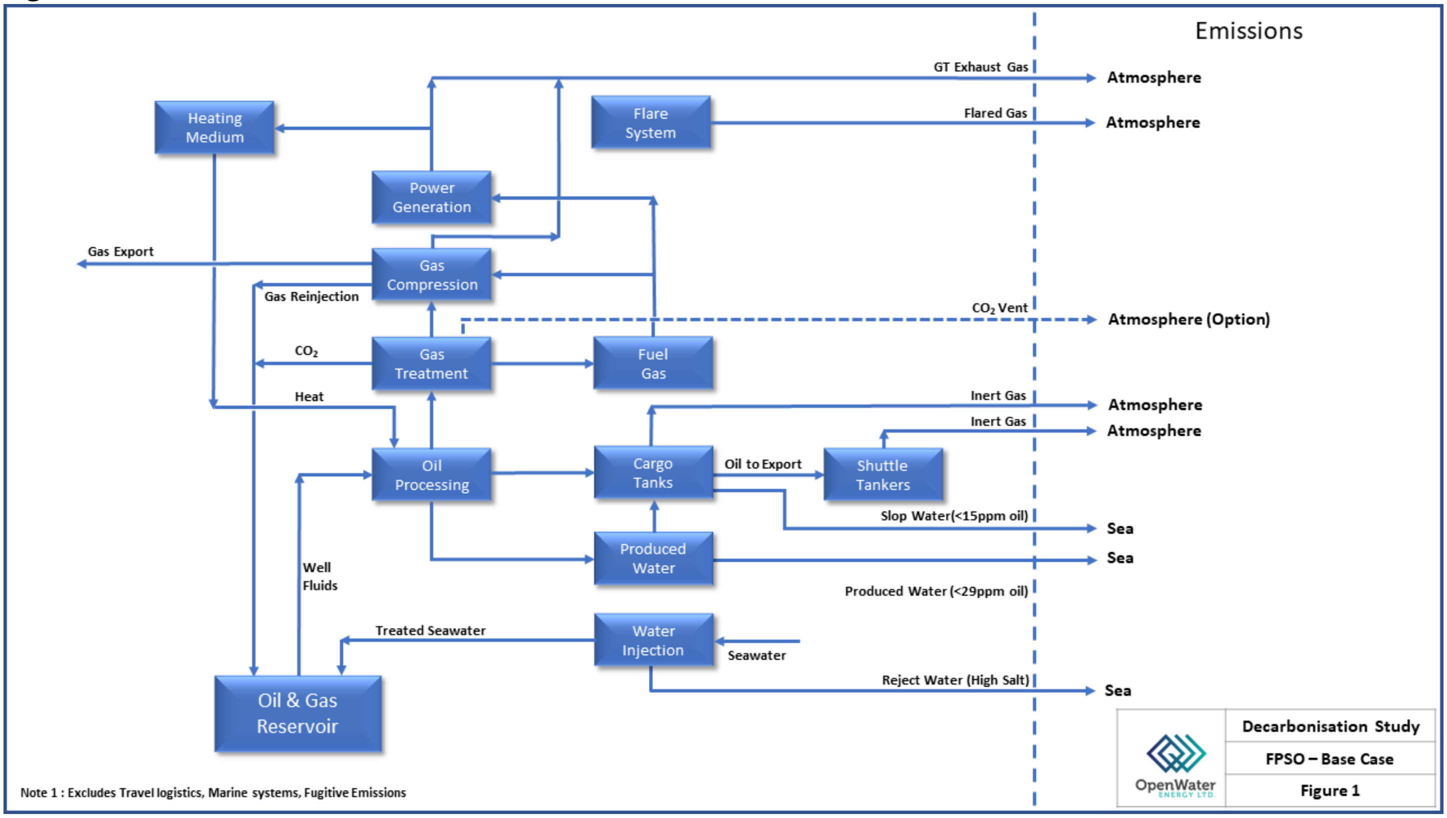


Figure 3

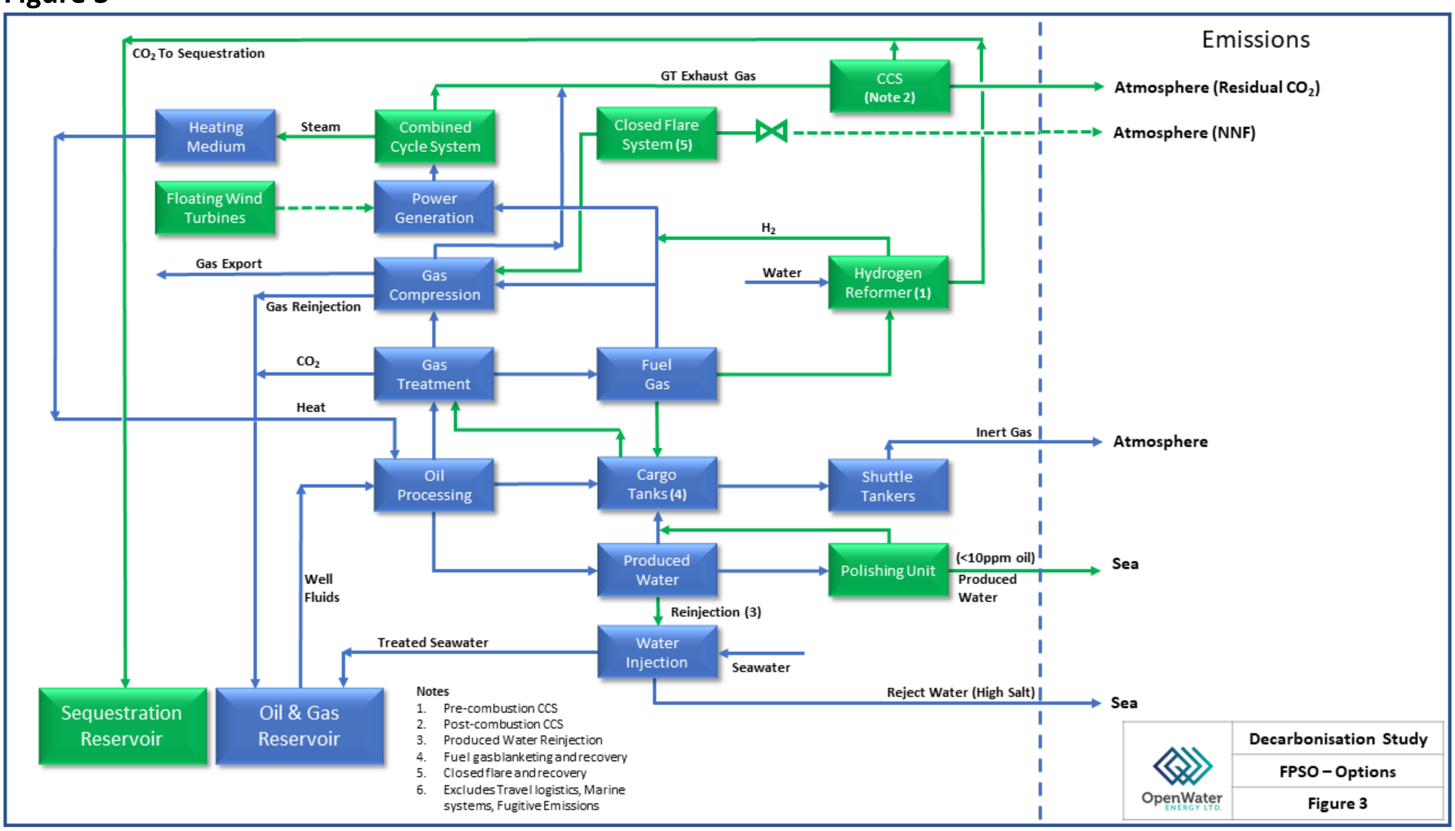
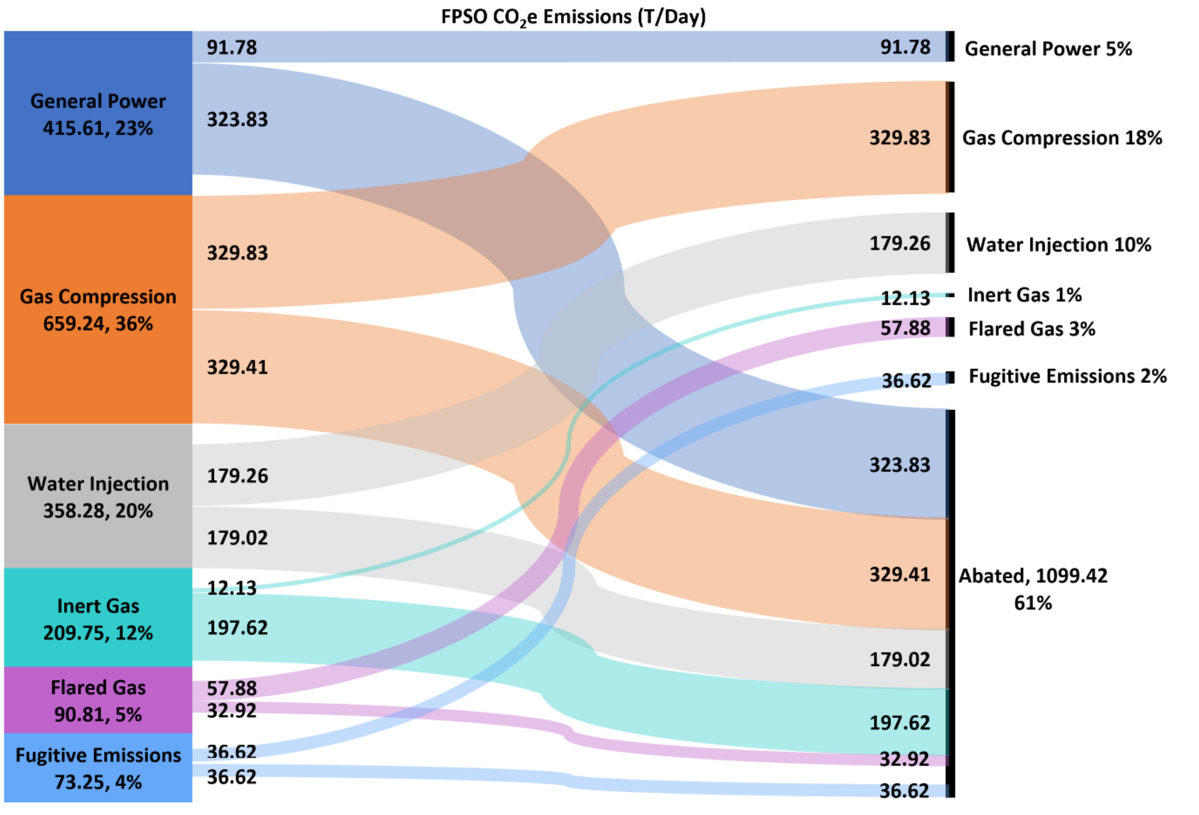


Figure 5



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